THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

A REPORT ON
CACAO RESEARCH

1954

ST. AUGUSTINE, TRINIDAD, B.W.I.

9 DEC 1955

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ST. AUGUSTINE, TRINIDAD, B.W.I.

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

Incorporated by Royal Charter in 1926

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Introduction

RESEARCH work on cacao has suffered a very severe loss in the premature death in his forty-sixth year of Professor R. E. D. Baker. He was first appointed lecturer in mycology at the College in 1933 ; three years later, on the death of Professor H. R. Briton-Jones, he was placed in charge of the department of mycology and plant pathology, being promoted professor in 1945. In 1949, when the chair of botany became vacant, the two departments were amalgamated and Baker was appointed professor of botany and plant pathology. Although mycology and plant pathology were his first love he soon widened his interest to include the systematic botany of flowering plants and the management of field experiments. His enthusiasm for expeditions was in keeping with these interests and the article in the last Report on the Anglo-Colombian cacao-collecting expedition, of which he was the leader, is evidence of his versatility. Obituaries have appeared in *Nature*, Vol. 174, p. 1128 and in *Tropical Agriculture*, Vol. 32, p. 159.

R. Nichols, junior plant physiologist, arrived in Trinidad on 29th January, 1954, and started work on plant hormone assays with a view to studying the possible rôle of auxins in the cycles of flushing, flowering and fruiting in the crop. To our great concern he developed poliomyelitis in August and was invalided home in September. He has, however, responded so well to skilled medical treatment that he expects to be able to return to Trinidad during the summer of 1955.

Research Results

The paper which appears first in this report is based on work over a period of years and in it are the considered views of the senior member of the research team. From the title it might be thought that the paper will only be of interest to entomologists, for it deals with the activities of a very small insect, but this is not so. Whereas most previous workers have believed that cacao-thrips is a primary pest of cacao and that damage caused by this insect's activities may cause the degeneration or even death of the tree, Fennah's research shows otherwise. Cacao-thrips can multiply rapidly and build up large populations only on cacao-leaves in which synthetic processes have become retarded. Such retardation, on a general scale, is associated with suboptimal levels, or ratios, within the leaf of mineral nutrients in a form in which they can be utilised. The occurrence of such nutrient unbalance is seasonal and its severity is indirectly governed by the physical and chemical behaviour of the soil at each picket under the rainfall of the wet season. Cacao leaves produced during the wet season at pickets on soils " of impeded drainage " (the phrase being used to cover a complex interaction) become infested with cacao-thrips. Should the latter be controlled by insecticides the effects of the adverse environmental conditions persist and the trees are unable to improve until these, in turn, have disappeared with the onset of drier weather.

If true, and facts and arguments are given in support, this is a highly significant conclusion. There appears to be a remarkable correlation between soil conditions, the vigour of the tree and its fruiting and its susceptibility to thrips. In the introduction to the last report we wrote : " In our outlook we must think of cacao research as one entity with branches and subdivisions parts of the whole. Research on cacao soils has no value except in relation to the cacao trees growing in them." We are steadily approaching the state when we can see the wood in spite of the trees, when we can visualise the interdependence of one branch of research on another and when we can see that they can be integrated to form one whole. There are many factors and integration is only possible when a research worker has spent years of study and thought on his subject and has accumulated sufficient evidence to give support to his reasoning.

The second article by Cope and Bartley is the natural outcome of the accumulation of knowledge in a different sub-division of the whole. It is a result of the consideration, in the light of work carried out at the College, of this statement. " The bulk of the world's cacao is produced from relatively low-yielding trees, the inefficiency of which becomes more marked the more the cost of production rises." The authors stress that the cacao population of Trinidad is the highly diversified product of four hundred years cultivation during which repeated introductions have been made from the mainland adding to the bank of genes, and thereby to the heterogeneity of the population. The first notable step towards improvement was made by Pound in the early 1930's, and in this article the authors evaluate nearly a quarter of a century's subsequent research. Such factors as yield, precocity, dependence on environmental conditions, pollen compatability, disease resistance and bean quality are surveyed before consideration is given to the criteria on which selection of desirable clones should be made. Much has been done ; a vast amount remains to be done ; but, whereas pioneer work in the past involved groping in the dark there is now enough related knowledge to enable future work to be far more effective. The authors estimate that the average annual yield in Trinidad is about one pound of dry fermented cacao beans per tree. This is clearly not good enough.

In his fourth paper on the interactions of shade and fertilisers on the growth and fruiting of cacao, Murray surveys what happens when trees, formerly grown under varying amounts of shade, are now grown in full light. The effects are precise and are clearly illustrated graphically in the text figures. Whilst removal of shade led to an immediate loss of leaf, within six months the trees had made such excellent new growth as to form closed canopies.

The crop production is equally striking. For plants previously grown in 15% to 25% of full light, i.e., in heavy shade, removal of shade practically doubled the crop. At 50% light the effect is less marked but still significant. The most interesting observation is that whilst trees growing in heavy shade show little response to nitrogen fertiliser these same trees, on removal of the shade, showed a marked response. Clearly under higher light incidence they were able to utilise the nitrogen stored in their tissues during the previous period in shade. Of considerable interest also is the changing requirement of nitrogen and potash in trees never grown under shade. Whilst in their early years the greater response was to nitrogen, now that self-shading is appreciable, the greater response is to potash. The results of this experiment have led to a far clearer understanding of the function of shade in cacao. Whilst additional factors, particularly water relations, require further study this interaction of shade and nutrition explains why trials in the past with one or other factor treated separately so often gave anomalous results.

Murray and Cope are investigating the importance of the stock in the performance of the scion grafted on it and trying to find out whether a composite plant yields more than either stock clone or scion clone on its own roots. As regards early growth, in general the effect of a clone on growth as measured by girth is greater as a scion than as a stock. An exception is in the combination of ICS 60 and ICS 45 where the vigorous 60 swings the balance in favour of 60 whether as stock or scion. The work is not yet complete, but the importance to the planter is clear. A single example illustrates this. ICS 1 while being fairly resistant to Witches' broom disease is intolerant of heavy soils with impeded drainage ; ICS 60 does reasonably well under such soil conditions, but is very susceptible to Witches' broom disease. ICS 1 scion on ICS 60 stock might form a possible combination for heavy soils in Witches' broom areas. This paper is of added interest in that it indicates how three sub-divisions of cacao research should be and here are dovetailed—genetic constitution of the clone, including resistance to disease, physiology of the tree and the physical state of the soil. It is clearly desirable that further experimental work along these lines should be carried out in a markedly contrasted soil type.

The short paper by Murray on periodicity of cropping in young cacao plants raised from cuttings records these facts. Plants, when just coming into bearing, yield most in the period of the late crop, April to August, but with increasing age a gradual change occurs resulting in proportionately greater yields in the main crop period from November to January. This change is strongly affected by the light intensity under which the plant is growing.

Rooted cacao cuttings, if handled by the propagation methods now standard in Trinidad, and despatched as soon as they are ready, are virtually free from insects. If, as often happens, they have to be held in the hardening shed they may become lightly infested with various pests. Fennah's investigation was designed to find an answer to this problem and in his paper on disinfestation of rooted cacao cuttings he shows that exposure to 30 gms. of HCN per 1,000 cubic feet for twenty-four hours at a temperature range of 86°F. to 89°F. and a relative humidity of 80–100% caused no injury to the plants and resulted in 100% kill of insects tested and 70% kill of millipedes. At 60 gms. HCN per 1,000 cubic feet all arthropods are killed, but some damage is sustained by the plant. With methyl bromide the gap between toxic level to invertebrates and the threshold of damage to the plants is so narrow that this fumigant cannot be recommended. A BHC smoke at heavy dosage failed to give control of mealybugs.

The breeding programme designed to evolve clones resistant to Witches' broom makes it imperative, in the absence of unlimited land for planting seedlings, to devise a method for inoculating the cacao plant to test its resistance or susceptibility. Clearly the earlier a reliable test can be applied, enabling the susceptible clones to be eliminated before field trials are set out, the better. Holliday's paper describes how he has effectively solved this problem and thereby provided a tool of considerable value to the breeder. The testa is removed from the ripe seed which is then placed to germinate on damp filter paper in a covered glass dish. In the evening of the fourth day each germinating seed is inoculated by a quick dip in a freshly prepared suspension of basidiospores, containing approximately 200,000 to the cubic centimetre. Immediately afterwards each seed is planted just below the surface of standard damp potting soil in a basket and kept in an open greenhouse. Susceptible seedlings show 100% infection in from nine days to a few weeks' time.

In his survey of the minor insect pests of cacao in Trinidad, Professor Kirkpatrick deals with the aphids. Two species are described with their habits and their predators.

The paper on manurial and cultural experiments (part IV) by Havord, Maliphant and Cope reports very complicated results, often conflicting with previous work. It might be criticised as presenting a progress report rather than an account of a completed phase. However, as it deals with a long-term experiment it cannot be a final account of the work on the subject. It is important that the complexity of the problem, and the fact that there may be well marked interactions between shade, spacing, and responses to fertilisers, should be appreciated. Work on the effects of fertilisers on any stage of the cropping cycle is now considered valueless unless conditions of shade and spacing are specified ; this has often not been so in the past. These complications may explain discrepancies between different experiments on the subject.

The fifth paper of the series on manurial and cultural experiments by the same three authors presents further evidence on the performance of various clones at selected sites. Some are precocious, others mature late ; some vary widely in performance from tree to tree, others are more uniform in yield ; and the effects of soil treatments on early yields vary widely from tree to tree. The whole picture is not yet clear but it is evident that all factors which affect growth, development and maturity must be studied and understood before final statements can be made as to the value of specific clones.

Havord's paper on soil heterogeneity serves to emphasise that the cacao tree is extremely sensitive to variations in the physical status of the soil. Each member of a group of trees only a few yards apart may behave differently. This is another pointer to the truth, which is becoming more and more realised, that very localised variations in soil conditions are a common feature in Trinidad soils and that such variations have a profound effect on the performance of the cacao tree. It is also a pointer to the fact that much of Trinidad's cacao land is poor.

The paper on lime-induced chlorosis of seedlings, also by Havord, presents rather remarkable results. Cacao seedlings can be grown in a soil containing as much as

30% calcium carbonate provided that the organic matter of the soil and the watering régime are similar to those in the experiment. Where chlorosis occurs in seedlings grown in a soil rich in lime and deficient in organic matter it appears to be due not to failure of the plants to take in iron from the soil but, for some reason not understood, to interference with the role played by iron in the formation of the green pigments.

The " chocolate flavour " of cacao is not perceptible in the raw beans ; it is not until they are fermented and roasted that the characteristic flavour develops. It is probable that the precursor or precursors of the flavour are affected by many factors during the process of fermentation by both anaerobic and aerobic bacteria and fungi. It is possible that flavour is also affected by the genetic constitution of the crop. Properly fermented and dried West Indian beans have for many years commanded a premium in world markets because they develop desirable flavours ; blended suitably with bulk cacaos, a fine full-flavoured chocolate can be produced. Nobody knows why some West Indian samples are better flavoured than others, but it is clearly desirable that the causes should be known. Are the differences due to climatic or soil conditions, to correct fermentation under expert supervision, to admixtures of beans from hundreds or even thousands of seedling trees, or do all these play their part? If desirable flavour elements are inherent in some clones and not in others this should be determined ; if it does not matter what the clones are, provided that a great mixture is present in the fermentary, this also should be known. It is equally important to understand the process of fermentation and the part played by different organisms and their by-products.

Unfortunately " chocolate flavour " cannot yet be assessed by exact scientific techniques ; it is appreciated by the senses of taste and smell and touch and no two individuals register precisely the same result. For this reason the large business firms have their expert tasters who train their palates to recognise just what their particular firm wants. It is an art, like tea tasting, acquired by long practice and a profound knowledge of the firm's products. Clearly such methods cannot be applied in Trinidad unless we have our own tasters trained by an experienced firm. Clearly also we should not aim at evaluating the products in the light of one firm's experience and requirements.

To break new ground we have tried new methods. We have established panels of tasters, who sample chocolate made to a precise formula by a standard technique and who state what they taste in terms of intensity of chocolate flavour, acidity, bitterness, etc. De Witt in his article has described the difficulties experienced and has critically analysed the results. His article is worthy of study by men who know a good chocolate. We quote one sentence which forms the key to our approach. " Since the function of the taste panel, broadly speaking, is to distinguish only the very good and the very bad from the mediocre samples, in order to guard against the introduction of inherently poor cacaos and to indicate the better ones, a high degree of precision is not as important as a high capacity." We do not profess to have solved the problem of assessing flavour, but we consider that we have gone some way to evolving a technique for recognising the best and the worst with a view to elimination of the latter.

Conferences

At the fifth meeting of the Inter-American Technical Cacao Committee, at Turrialba, Costa Rica, the staff of the Cocoa Research Scheme were represented by G. Havord and Paul Holliday. Papers presented were : " Mulching for Cacao," by G. Havord, " Control of Witches' Broom and Black Pod Diseases in Trinidad," by Paul Holliday and " A New Method of Vegetative Propagation," by D. B. Murray.

Cocoa Board

Mr. Murray was appointed a member of the Cocoa Board, the body responsible for the rehabilitation of cacao in Trinidad and Tobago and more especially for the production of rooted cuttings for estate planting. In this connection demand for plants so exceeds the capacity of the Board's propagating stations that the plant physiology section was asked to utilise its propagating facilities to the fullest extent, the cost of production being met by the Cocoa Board. Some 12,000 plants were produced at the College during the year, including those used for planting at River Estate.

Despatch of planting material

Cuttings were taken from all the available cacao introductions made by the Colombian expedition and sent to Kew by Wardian case. Seedlings of other *Theobroma* and *Herrania* species were sent at the same time. Budwood and cuttings of several of the ICS clones were sent to St. Vincent and Puerto Rico for quarantine purposes and later distribution. Negotiations are still in progress towards securing budwood of Lafi No. 7, the Samoan Black pod resistant clone.

The Epidemiology of Cacao-thrips on Cacao in Trinidad

by

R. G. Fennah

MOST workers who have come in contact with the problem have speculated on the nature of the factors which govern "outbreaks" of cacao-thrips (*Selenothrips rubrocinctus* Giard). The points of view from which the subject has been approached are very diverse : on this account it is considered preferable not to attempt an historical résumé, but to begin with a presentation of data and to evaluate the contributions and opinions of previous workers in a general discussion

Life History of Cacao-thrips on Cacao

The life history of cacao-thrips is, briefly, as follows. The eggs are laid singly below the epidermis on the underside of the leaf, and hatch in approximately twelve days. The nymphs feed in groups on the lower surface of the leaf for about ten days and undergo two moults. After the second moult the nymph does not feed for twenty-four hours, at the end of which it moults again to become a non-feeding pupa. After two or three days in this stage it undergoes its final transformation to become adult. Soon after emergence the female is able to lay eggs, of which she may produce up to fifty during her life-time of about a month. The total length of the life-cycle is thus slightly less than a month. All stages of the life history on cacao are passed either on the lower surface of the leaf or on the outer skin of maturing pods.

Host Plants

Cacao-thrips feeds on the leaves of a moderate number of unrelated shrubs and trees. Its hosts are reported to include hog plum (*Spondias monbin*), guava (*Psidium guajava*), *Psidium polycarpon*, anatto (*Bixa orellana*), avocado pear (*Persea americana*), pomme rose (*Eugenia jambos*) and other species of *Eugenia*, cashew (*Anacardium occidentale*), almond rose (*Terminalia catappa*), mango (*Mangifera indica*), *Cola acuminata*, sea-grape (*Coccoloba uvifera*), *Coccoloba latifolia*, *Canarium commune*, *Triplaris surinamensis*, wild cotton (*Gossypium*), *Zanthoxylum martinicense*, grapes and roses.

It has not, so far, been found on all of these in Trinidad. *Selenothrips* is by no means a general feeder, and a cursory survey of this list does not immediately suggest what attractant guides the selection of host plants of such remote botanical affinity. The factor which is obviously common to most of them is the presence of an essential oil, or a mixture of two or more, and it is possible that the identifying substance is of this nature.

Zonation of Attack on Host Plant

(*a*) ON CACAO

Counts were made on leaves of trees at two sites, one on an extensive alluvial flat, the other on broken and dissected topography in the Central Range, and were carried out in late October at the peak of a thrips outbreak.

In Table I a sample is given of selected entries which are indicative of the general result. The leaves of each flush of growth are numbered separately, beginning with the youngest. Group A comprises only flaccid immature foliage and newly-hardened leaves of the same flushing period; Group B comprises the hardened leaves of the September flush, and represents the youngest of the mature foliage on the plants ; Group C, next in age to the preceding, comprises leaves of the July flushing period and includes all older foliage.

In cacao, especially if shaded, groups of leaves from different branches cannot be objectively judged as being of equal age or not, even though the relative age of leaves on any one branch is quite evident. The fifth leaf from the apex of a shoot, for example, is sometimes an uninfested leaf of the immature flush, and sometimes a highly infested leaf of the previous flush. The average figure from grouped data would suggest the presence of a moderately-infested leaf in between non-infested and highly-infested leaves : this would be misleading, as a leaf so infested does not occur on lateral-branch foliage in the field, and can only be sought with confidence on the graded foliage of watershoots.

It is for this reason that the sample given in Table I is considered to give a truer picture of what is actually seen in the field than an average of the total.

As can be seen, the differences in degree of infestation of flushes of different ages are clearly defined, and the general relationship (in the period between September and March) is as follows. The apical flush, as long as it consists of flaccid leaves, is free from infestation. Leaves of the previous flush, which are fully hardened, are heavily attacked : those of the next older flush may or may not be infested, but, if at all, are invariably more lightly so. Old leaves are not infested. Watershoots, which usually arise under the shade of the cacao canopy, have the physiological characteristics of a slowly expanding flushing shoot : the time interval between the age of the youngest leaf and of the oldest may be broadly comparable with, if not actually as long as, that between a young flush and its predecessor on a lateral branch. On a watershoot the leaves are separated in age by approximately equal time intervals, and the gradation from youngest to oldest may be perfect. On such shoots, in contrast to lateral branches, cacao-thrips attack may show a gradation in intensity down the shoot, in conformity with increasing age of leaf. Leaves of young chupons (after horquetting) are affected to a

degree corresponding to that of foliage of similar age on the lateral branches.

The picture, however, is still not complete. In unshaded areas attack by cacao-thrips is severe on the uppermost and outermost leaves of the tree: it may be significantly more severe in such places than elsewhere, as has been repeatedly noted (Reyne 1921, p. 199; Darling 1942, p. 151; Pound 1932, p. 33). Nevertheless, it is equally true that in substantial areas of lightly-shaded cacao the upper parts of the tree may remain obviously, and significantly, less infested by cacao-thrips than the lower. It is strange that this phenomenon has passed unrecorded: the only possible reference which the writer has been able to find is contained in the statement by Urich (Urich 1919, p. 86) that "All the time the leaves are young and not too tough and the rains are still on, thrips remain at the tops of the trees, but when the weather becomes drier they descend to the shaded pods and suckers. . . ."

TABLE I

Distribution of cacao-thrips in relation to age of leaf.

Shade		Moderate										Light									
Type of Tree (and Site)		Old Seedling (La Reunion)										ICS 1 (Sta. Maria)						ICS 95 (Sta. Maria)			
Type of Branch		Watershoot				Lateral						Lateral						Lateral			
Sample No.	Leaf Order	1	2	3	4	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4
A. Very young, flaccid leaves	1	0	0	0	0	0	0	0	—	0	0	0	0	—	0	0	0	0	—	0	0
	2	0	0	0	0	0	0	0	—	0	—	0	0	—	0	—	0	0	—	0	0
	3	0	—	0	—	0	—	0	—	0	—	0	0	—	—	—	1	0	—	0	—
	4	—	—	—	—	0	—	1	—	0	—	0	0	—	—	—	—	0	—	0	—
	5	—	—	—	—	—	—	0	—	—	—	—	0	—	—	—	—	0	0	—	—
Young mature leaves ...	1	3	1	0	0	—	—	—	6	—	2	—	—	4	—	—	—	—	0	—	—
	2	3	4	6	2	—	—	—	8	—	13	—	—	2	—	—	—	—	0	—	—
	3	—	1	15	7	—	3	—	4	—	5	—	—	10	—	—	—	—	0	—	—
	4	—	3	3	1	—	1	—	22	—	10	—	—	4	—	—	—	—	2	—	—
	5	—	1	0	4	—	5	—	9	—	—	—	—	21	—	—	—	—	—	—	—
B. Mature leaves	1	0	3	—	—	7	13	17	—	14	—	21	18	—	7	12	17	1	4	2	0
	2	0	0	8	—	4	9	8	—	3	—	38	13	—	13	27	6	3	0	6	4
	3	—	—	3	—	7	13	—	—	21	—	12	4	6	9	4	14	1	0	0	0
	4	—	—	1	—	—	—	—	—	8	—	26	11	2	21	11	21	0	7	1	7
	5	—	—	—	—	—	—	—	—	—	—	14	5	2	17	5	8	5	2	1	2
C. Old leaves	1	—	—	—	0	0	0	—	—	—	—	—	0	—	2	0	0	0	—	0	0
	2	—	—	—	0	0	—	—	—	—	—	2	0	—	0	0	3	0	0	0	0
	3	—	—	—	0	—	—	—	—	—	—	0	0	—	0	—	0	0	0	—	0
	4	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—	0	0	—	0
	5	—	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—	0	—	—	0
	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—	—	—
	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	—	—	—

There is a special case of leaf infestation which at first sight appears to constitute an exception to the above pattern. Sometimes, in the early dry season, a small apical flush may be found heavily attacked by cacao-thrips, even though its leaves may be only half of normal size, and of immature coloration. Such shoots, however, are young only in appearance: in fact they are physiologically mature, and the leaves are incapable of further growth in size; moreover, unlike that of young tissue, their texture is hard and brittle. This condition of foliar precocity will be discussed below.

Finally, cacao-thrips may occur in all stages on the surface of cacao pods. Only pods that are in an advanced state of development are liable to heavy infestation. Even then it is in special circumstances, and on certain trees, that such infestation reaches a high level: for the most part it is unremarkable.

(*b*) ON OTHER HOSTS

Observations of the distribution of attack on other hosts are still few. On *Bixa orellana*, examined after November, cacao-thrips were present, though sparsely, on all the foliage, which comprised only mature leaves. On cashew, cacao-thrips have been observed in abundance on mature foliage in January, and rather sparsely on the oldest leaves of watershoots when the younger leaves were free from infestation.

Abundance of Cacao-thrips in Relation to Time

Underlying the lesser fluctuations in the size of cacao-thrips populations there is a broad annual rhythm, of which two examples are shown diagrammatically in Fig. 1. The broken line, based on the account of Reyne (Reyne 1921, p. 200) is related to the yearly cycle in Surinam in which February and March are dry months, April to the end of July are the principal wet months, August to the end of November typically dry, and December and January typically wet. The solid line, based on the data of Urich (1919, p. 87), Callan (1943b, p. 317) and other observers, indicates the course of the yearly cycle in Trinidad in which February to the end of April are dry months, May to September are wet, October relatively dry and November to the end of January wet.

In 1949 the writer examined outbreaks in several diverse localities in Trinidad to determine whether the climax of

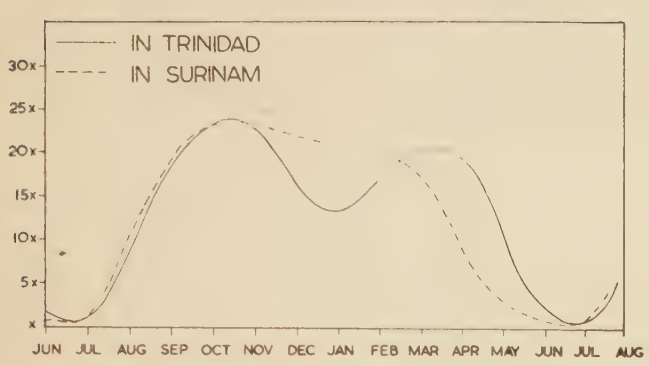

FIGURE 1

Diagram illustrating the typical annual cycle of cacao-thrips development. (The broken line is based on data given by Reyne.)

thrips attack occurred at the same time. Both the sample counts and the equally informative appearance of the leaves of the host plants showed that no appreciable differences existed between one site and another as far as time of culmination of attack was concerned.

The numerical data given by Reyne and by Callan (Fig. 2) illustrate the effect of minor fluctuations superimposed on the major trend. They show that the periods of maximum abundance, at a given site, do not conform rigidly to a monthly date, and suggest that there is little constancy in the absolute density reached.

Abundance of Cacao-thrips in Relation to Flushing

It was realised that further counts of cacao-thrips, expressed simply in terms of time, would merely illustrate further possible fluctuations in abundance within the broad annual curve, without providing any clue to their cause. It was, accordingly, decided to take a small number of branches and to follow their foliar history in relation to the incidence of cacao-thrips. Observations were begun at two sites, one in the Caroni flood-plain and one in the Central Range, in June, at a time when the cacao-thrips population was minimal. In Table II the results are given of counts of branches from trees on the first site. At the beginning of these counts the leaves were numbered from the base of the shoot to the apex, so that number one is the oldest leaf on the branch, and the remainder apply to leaves strictly in the order in which they were produced. At this site the branches were on old trees of seedling origin.

The data obtained at this site were found, by cursory inspection, to be representative of what occurred elsewhere in the same area. Furthermore, they were in perfect agreement with the results obtained on the Central Range site, which also were typical of its surrounding area.

If the data of Table II are averaged, and the degree of infestation is plotted against time (in months), it will be seen that the shape of the curve is in general conformity with that for the annual cycle. There is reason to believe that the pattern of population-increase which Table II reveals is typical of the general annual trend of cacao-thrips abundance, and that the mechanism which has affected the development of cacao-thrips on these few branches is fundamentally the same as that which affects the development of cacao-thrips populations on all other branches elsewhere in the Colony.

The data show that in this field there were three main flushes of growth, one in June, one in late August and early September, and one in February. Leaves produced in the June flush remained free from cacao-thrips until well on in August, after which they became infested to a moderate degree. The cacao-thrips attack reached its height in October and ceased before November. Leaves of the September flush, by contrast, were massively attacked in the following month, and the maximum density of infestation was much higher than on the older leaves. This attack was sustained into November but subsided to a low level before December. Leaves of the February flush were attacked as soon as they began to harden, and a substantially large population of cacao-thrips was built up.

An interesting point, not evident from the data but readily observable in the field, was a change in the character of the infestation when on the decline. Prior to, and during, the peak of the attack many groups of cacao-thrips were present on the leaves, and individuals wandered freely over the surface. In November, after the peak had been passed, cacao-thrips were relatively scarce on open tracts of the lower leaf surface, and tended to remain grouped below small webs made by spiders or other arthropods. The association was so marked that it appeared likely that this degree of shelter was responsible for survival of the insects.

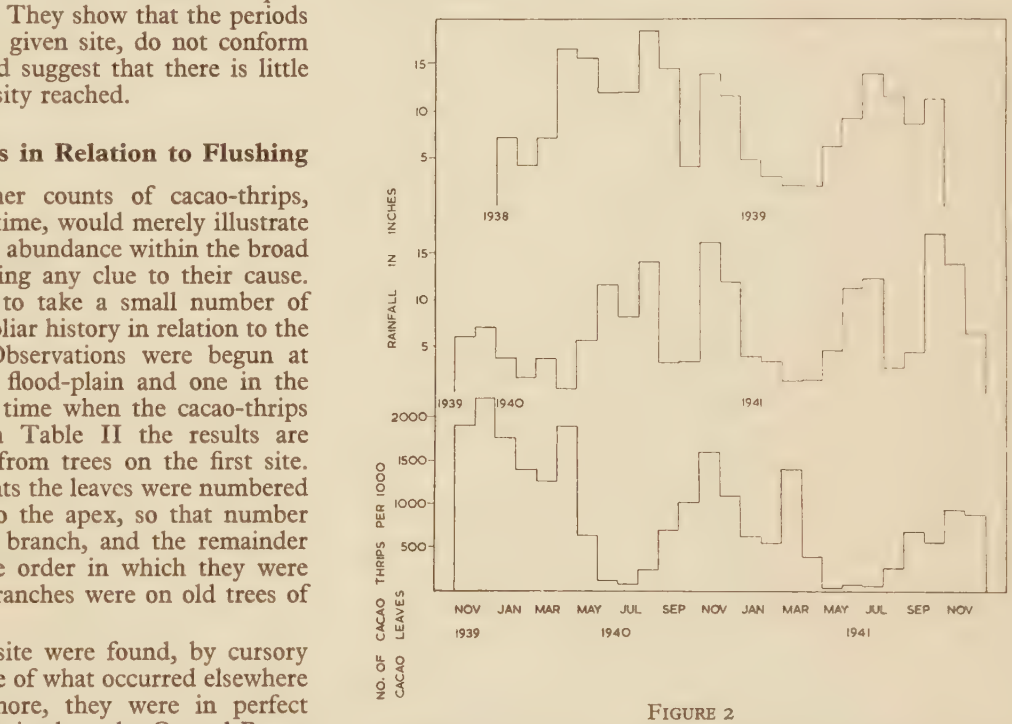

FIGURE 2

Histogram showing relative monthly abundance of cacao-thrips at one site (data from Callan), with rainfall for the preceding and corresponding period.

Abundance of Cacao-thrips in Relation to Yearly Weather

While the annual cycle of development of the cacao-thrips population follows the broad pattern described above, the absolute height reached by the peak of the curve, as determined by a standard counting method, varies, in any one spot, from year to year. No direct

TABLE II

Incidence of cacao-thrips in relation to time of leaf production (La Réunion)

Leaves numbered in order of development	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	0	—	—	—	—	—	—	—	—	—	0	0	—	—	—	—	—	—	—
2	0	—	—	—	—	—	—	—	—	—	1	0	—	—	—	—	—	—	—
3	0	—	—	—	—	—	—	—	—	—	0	0	11	—	—	—	—	—	—
4	0	—	—	—	—	—	—	—	—	—	0	1	8	12	0	0	0	0	0
5	—	3	2	—	—	—	—	—	—	—	0	0	4	19	0	0	0	0	0
6	—	0	4	—	—	—	—	—	—	—	0	0	0	4	3	0	0	0	0
7	—	0	1	—	—	—	—	—	—	—	—	—	0	14	0	0	0	0	0
8	—	0	0	—	—	—	—	—	—	—	—	—	0	2	0	3	2	0	—
9	—	0	1	5	—	—	—	—	—	—	—	—	0	5	8	0	2	3	—
10	—	0	0	1	—	—	—	—	—	—	—	—	—	0	7	5	0	—	—
11	—	—	—	0	9	0	0	0	0	—	—	—	—	0	0	0	0	—	—
12	—	—	—	0	13	2	1	0	2	0	—	—	—	0	5	2	1	—	—
13	—	—	—	0	15	10	4	4	0	0	—	—	—	—	—	—	—	0	3
14	—	—	—	0	3	1	4	3	—	—	—	—	—	—	—	—	—	0	2
15	—	—	—	0	7	4	0	0	—	—	—	—	—	—	—	—	—	0	0
16	—	—	—	—	—	—	—	—	0	6	—	—	—	—	—	—	—	0	0
17	—	—	—	—	—	—	—	—	0	7	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	0	0	—	—	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—	0	3	—	—	—	—	—	—	—	—	—

Leaf No.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	—	—	0	2	8	3	0	0	0	—	0	0	2	—			—	—	—	—
2	—	—	0	3	14	6	1	0	0	—	—	0	0	2	—	—	—	—	—	—
3	—	—	0	1	7	6	0	2	0	0	—	0	0	1	8			—	—	—
4	—	—	—	0	3	2	1	0	2	1	—	0	2	4	12	—	—	—	—	—
5	—	—	—	0	0	1	3	5	1	0	—	0	0	1	10	14	—	—	—	—
6	—	—	—	0	1	4	0	0	—	—	—	0	0	4	11	3	0	0	0	—
7	—	—	—	—	—	—	—	—	2	8	—	—	—	0	0	4	7	0	0	—
8	—	—	—	—	—	—	—	—	0	3	—	—	—	—	0	2	5	2	0	—
9	—	—	—	—	—	—	—	—	0	2	—	—	—	—	0	0	2	6	2	0
10	—	—	—	—	—	—	—	—	0	0	—	—	—	—	0	0	5	2	0	0
11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
13	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
14	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0

Leaf No.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar
1	0	0	2	8	—	—	—	—	—	—	0	0	0	—	—	—	—	—	—	—
2	0	0	0	—	—	—	—	—	—	—	0	0	0	7	—	—	—	—	—	—
3	0	0	0	0	—	—	—	—	—	—	0	0	0	12	9	0	—	—	—	—
4	0	0	1	0	12	6	0	0	—	—	0	0	4	5	12	0	0	0	—	—
5	—	—	—	0	0	14	2	0	—	—	—	—	—	0	18	7	0	0	—	—
6	—	—	—	—	0	4	0	1	—	—	—	—	—	0	6	9	2	—	—	—
7	—	—	—	—	0	1	7	0	—	—	—	—	—	0	5	5	2	—	—	—
8	—	—	—	—	0	4	0	1	—	—	—	—	—	—	—	—	—	0	13	2
9	—	—	—	—	—	—	—	—	0	4	—	—	—	—	—	—	—	0	5	11
10	—	—	—	—	—	—	—	—	0	1	—	—	—	—	—	—	—	0	1	9
11	—	—	—	—	—	—	—	—	0	8	—	—	—	—	—	—	—	0	1	13
12	—	—	—	—	—	—	—	—	0	5	—	—	—	—	—	—	—	—	0	—

association has yet been sought between absolute cacao-thrips abundance and climatological data by quantitative methods. Climatologically, the extremes of contrast in types of annual weather are usually expressed in terms of a single characteristic, namely, rainfall. As a broad generalisation, the rainfall in a " dry " year is about 60% of that in a " wet " year, measured at any one site.

The monthly rainfall for the period 1938-1941 measured at a site in the Central Range is shown in Fig. 2 alongside Callan's data for relative abundance of cacao-thrips for part of this time. The site where Callan's data were collected is on a clay soil. Pound (1939, p. 30) noted that on a badly drained clay soil at Marper Experiment Station very heavy rainfall was followed by a substantial reduction in crop in the following year. Such reduction is attributed to various factors of which cacao-thrips is one. The relationship noted at Marper does not hold good on other soil types (as at River Estate, for example), and it is highly probable that the relationship between " wet " or " dry " years and degree of cacao-thrips incidence is determined by soil type.

There is no traditional association between extremes of weather and abundance of cacao-thrips. The data given in Fig. 2 are not inconsistent with a possible association of great abundance of cacao-thrips *at this site* with a relatively high moisture content of the soil, but, at present, the suggestion can be pressed no further.

Topographical Survey of Cacao-thrips Incidence at a Single Site

It has long been recognised that trees heavily infested with cacao-thrips often occur in small compact groups, and have a history of susceptibility to exceptional damage.

In the present investigation a site was chosen on soil of good characteristics (very broadly considered), bearing trees among which no serious " thrips pocket " of conventional standard could be found. At this site (Cheesman Field, San Juan Estate, Central Range) overhead shade, provided by immortelle (Anauca) was uniform and rather light. The cacao-trees were fourteen years old and of relatively uniform growth, and comprised five replicates of the ICS clonal series 1 to 100, planted serially (Fig. 4).

After a preliminary inspection in early October had shown that an attack of cacao-thrips was imminent, its severity at each planting site (picket) was estimated by inspecting the tree which occupied the spot. The abundance of cacao-thrips was estimated by rapidly examining the leaves of the last hardened flush (of September) to establish that cacao-thrips, if present, were distributed over the flush with reasonable uniformity, and by counting the nymphs on two of the leaves (a flush comprises about six). The counts were made with the aid of a pair of " Speera " 4x spectacles. The data gave approximate maximum infestation at the time of examination, which was known to be near its peak, and was found, in a cursory examination made in November, to have been actually at its peak. The total infestation for the season (that is, from June onwards) was estimated, after a brief check for reasonable uniformity, by counting the sites of earlier thrips colonies on two of the leaves, and also on two of the currently infested leaves. It had been decided at the outset that flushes selected for counting purposes should be among the most heavily-infested to be found (as indicated by discoloration and excrement) : in practice it was found that infestation of the same flush on each tree was sufficiently uniform to make the task of selection quite simple. Nymphs were counted on leaves which could be reached from the ground ; damage inflicted by earlier thrips colonies could be readily observed even in the uppermost parts of the canopy. As the attack was fairly heavy, the range in incidence was wide : moreover, the two sets of data were not contradictory. It was, accordingly, possible to reduce the data to seven arbitrary degrees of infestation, defined, as closely as possible, as follows : Class 1 : *nil* : no thrips ; no sign of thrips colonies. Class 2 : *negligible* : one specimen found ; or one sign of earlier thrips. Class 3 : *light* : two specimens found on the two leaves examined ; not more than the lightest signs of colonies on older leaves. Class 4 : *light to moderate* : two or three nymphs ; distinct signs of mild attack on older leaves and latest flush. Class 5 : *moderate:* three to five nymphs ; evident signs of damage to older leaves, with two colony-sites, or one large colony-site, per two older leaves counted. Class 6 : *rather heavy:* five to fifteen nymphs ; two to four colony-sites on the older two leaves, or unmistakable injury in quarter or half square-centimetre units. Class 7 : *heavy:* sixteen or more nymphs ; more than four colony-sites on the older two leaves, or large dead areas.

The signs of earlier presence of thrips include (*a*) small patches of epidermis covered with russet and wart-like papillæ ; (*b*) dead groups of cells associated with pitchy spots of dried excrement ; (*c*) a dead, dark brown area, with traces of excrement or marginal injury as in (*a*). The number of classes of infestation adopted was the largest that could be used without the number of " borderline cases " being inconveniently high. In the four hundred and fifty-odd paired sets of data examined their number proved to be quite small.

The data are summarised in Fig. 3, which shows the site (picket) of every tree in the field, and, if the tree was alive, its class of infestation.

In another survey in late February nymphs were counted on two leaves near the base of the January flush ; it was also established qualitatively that the cacao-thrips population had largely disappeared from leaves older than the January flush, though the marks of its presence were still abundant. This second survey, as far as distributional pattern was concerned, faithfully repeated the results of the first : it was, however, not complete, as some of the trees had not flushed in the interval since the first survey. The data from each tree were found to be consistent when the results of the two surveys were compared, though the renewed attack had not reached the intensity of the first at its peak. The *relative* degree of severity of attack at each picket at any given time after June conforms to the pattern shown in Fig. 3, as this remains practically constant whether comparison of trees is made on the basis of old scarifications or of October or February nymphal counts separately.*

It is clear from the data that the population of cacao-thrips has been distributed across the field at any one time as shown in Fig. 3 ; in other words, that this distributional pattern has remained rigorously fixed from its earliest formation in the wet season right through to the dry season. Cacao-thrips in the adult stage are active and highly mobile, and are capable of dispersing from any point through a two-acre block of trees such as those on Cheesman Field. In the present case they may well have done so : but, if so, they have not changed the distributional pattern of nymphal abundance. Alternatively, it is conceivable that they have preferred, after a period of scouting, to oviposit on newly-produced leaves of previously heavily infested trees. In either event the result is illuminating and will be discussed below.

Abundance of Cacao-thrips on Cacao in Relation to Genetic Constitution of Host

Callan (1943a) found in a population of seedling cacao several trees which escaped attack at a time when cacao-thrips were abundant, and was able to show that one of them remained uninfested and unattacked under a range of experimental conditions. Such a marked degree of resistance is not common, but a wide range occurs in natural susceptibility to infestation and in tolerance of injury.

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* The comparison of data on these bases was actually carried out by reducing the classes of infestation to three. The results were highly congruent, and in such obvious agreement with Fig. 3 that statistical analysis of the data was superfluous.

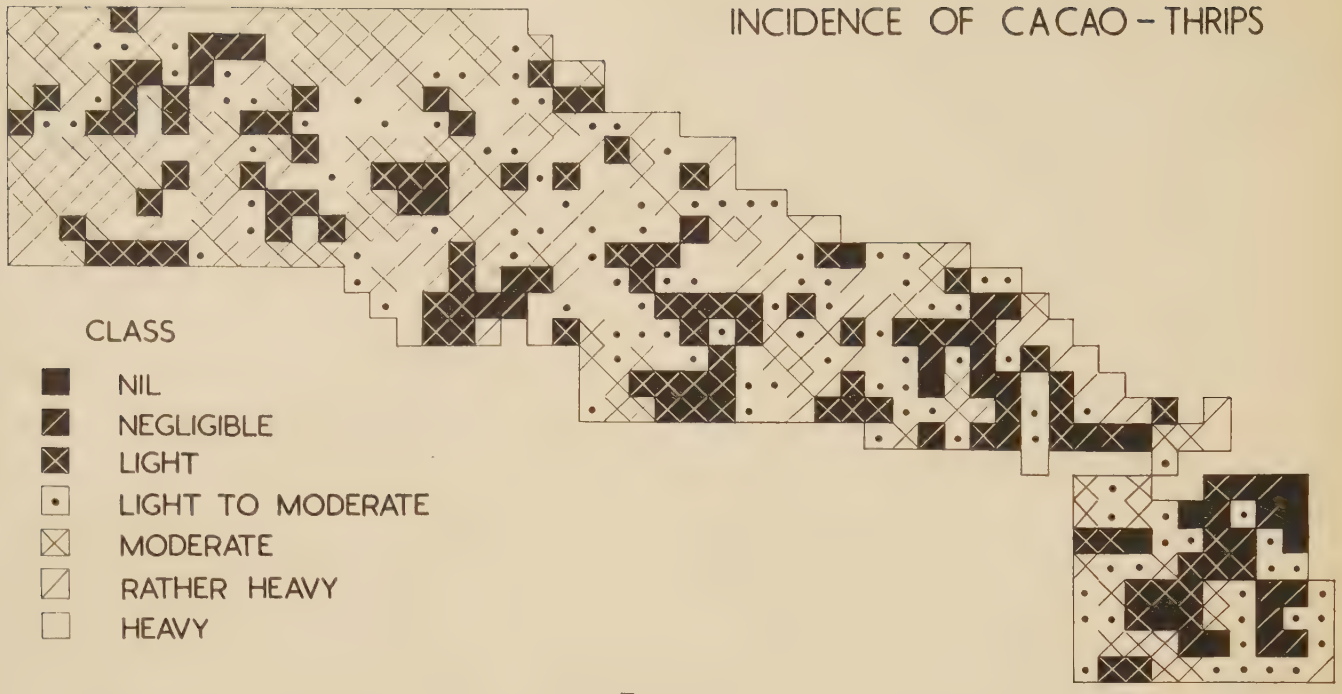

FIGURE 3

Plan of pickets on Cheesman Field, San Juan Estate, showing abundance of cacao-thrips on each tree in October.

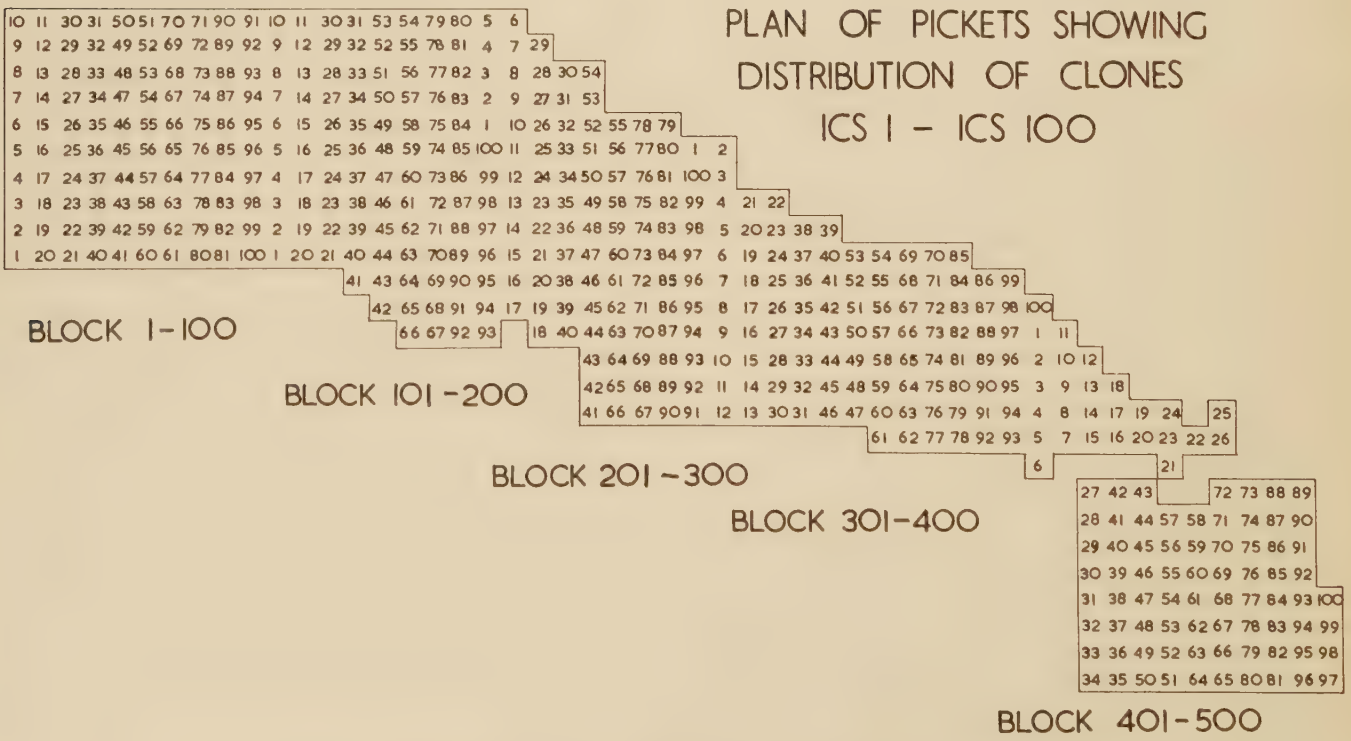

FIGURE 4

Plan of pickets on Cheesman Field, San Juan Estate, showing position of each ICS clone.

In the Cacao Shade and Fertiliser Experiment at the Imperial College of Tropical Agriculture (for the layout of which see Evans and Murray 1953, p. 68) it proved possible, even with a very light infestation by cacao-thrips, to find a difference in the number of trees of ICS 1 that were attacked by cacao-thrips and the number of ICS 95 similarly attacked. More trees of ICS 1 were attacked than of ICS 95, and the difference was significant (with P=0.02). In field observations, when cacao-thrips have been abundant, it has been noted that ICS 60 is obviously superior to ICS 1 in tolerance of attack. In the Cacao Shade Experiment the number of trees of ICS 60 attacked by cacao-thrips was not significantly different from the number of ICS 1, but as the general incidence of thrips was slight no conclusions are justified. The difference in degree of infestation shown in Fig. 3 between trees Nos. 60, 160, 260, 360, 460 and 1, 101, 201, 301 and 401 respectively, amply demonstrates the superiority of ICS 60 to ICS 1 in this field. ICS clones Nos. 73, 89, 90, 92 and 95 all show significantly less infestation than ICS 1, and appear to escape heavy attack even in the poorest areas at this site.

As clones ICS 1 and ICS 95 have been widely used for replanting purposes comparison of their relative performance with respect to attack by cacao-thrips is possible on a wide range of soil types. To judge from observations it would appear that the relative standing of these clones never changes. Both, in seriously adverse environmental conditions, may be heavily attacked, and both frequently escape attack. So far, however, no example has been found in which ICS 95 was infested more heavily or sustained more foliar injury than adjacent ICS 1.

Abundance of Cacao-thrips in Relation to Growth Habit of Cacao

The headings of this and of the following section suggest the existence of dependent and independent elements in the relationship mentioned. It is, perhaps, advisable to explain that they have been chosen merely as a " short title " to cover the presentation of data on the growth and yield of each tree on the Cheesman Field site. The appropriate inferences regarding the relationship are drawn in the subsequent discussion.

The leaf-bearing axes of a cacao tree comprise (*a*) watershoots, or vertical shoots with relatively widely spaced leaves ; (*b*) horquetted chupons, in which the vertical axis forks abruptly into about five obliquely radiating limbs, each of which bears alternately arranged leaves ; (*c*) lateral (fan) branches bearing alternately arranged leaves. It is with the last that this discussion is concerned.

A juvenile or vigorously growing " fan " branch comprises a single stem, and is often pendent at the end, like a fishing rod. It bears a row of leaves on each side, and these, usually in groups of five to eight alternated leaves represent the accumulated output of successive flushes of growth. Such branches are, accordingly, densely clothed with foliage, and when a flush of new leaves is produced, do not " change leaf " wholesale : some half-dozen leaves may be abscissed, one by one, near the base of the limb as the new shoots expand : sometimes a single leaf, or perhaps two, immediately behind the expanding bud may turn yellow and be abscissed.

The condition in a fan branch on a tree of retarded growth is in marked contrast to that just described. The hormonal dominance of the apical bud appears to become suppressed and lateral branchlets are produced ; sooner or later the process is repeated and branchlets of a lower order are developed. Leaves are shed at an early stage from the main axis, and thereafter only the current flush of leaves, or this and its immediate predecessor, are present on the branchlets at any one time. Fields in alluvial areas of impeded drainage usually contain many trees on which all the leaves are of practically the same age, or differ only in a narrow span of time, and occur in groups of four to six, each group at the end of an extensive system of dichotomous branchlets and resembling a single palmately-compound leaf.

These extreme types of branching habit are connected by a range of intergrades which can be broadly classified by counting either the number of flushes which are represented in the foliage that they bear at one time, or by counting the number of leaves on either of the best single limbs on the tree or of a random few of the uppermost branches and averaging the result. The differences which can be so measured reflect the continuous response by the whole plant to factors influencing the environment of the roots, and can be used as a means of mapping the distribution of such factors. A further indication of relative growth is afforded by the girth of the trunk, the stoutness of the main limbs, and the magnitude of the " scaffold."

Such data are of most value where the genetic constitution of the trees is known.

A survey was made of the clones in Cheesman Field and each tree was allotted to one of five arbitrary classes based on scores. The score made by each tree represented the average of the grades in which it was placed in the following system of assessment : *trunk girth* : (1) stout (8 inches in diameter) ; (2) average (5-8 inches) ; (3) thin (less than 5 inches) ; or *main limb girth* at about 3-4 feet from ground : (1) stout (more than 5 inches in diameter) ; (2) average (3-5 inches in diameter) ; (3) thin (3 inches or less in diameter) : *branching habit:* (1) most terminal branches long, some forked ; (2) few terminal branches long, branches mostly forked near apex, subdivision moderate ; (3) one long terminal branch or none, subdivision very marked, apical branchlets little longer than a normal leaf-petiole : *leaf density* : (1) ten or more leaves on the majority of single apical branches ; (2) seven to ten leaves on the majority of such branches ; (3) less than seven leaves on the majority of such branches. The leaf density assessment in each case consisted of a rapid qualitative appraisal of the uniformity of the canopy followed by a count of three or four terminal branches, from which an average was obtained.

This method of classification gave a series of seven possible scores. In a cursory inspection of the field the difference between " excellent " and " very good " was not immediately obvious ; it was, accordingly, decided to unite these two scores to form a single class. At the other end of the scale, however, it was considered desirable to keep the " very poor " trees in a class by themselves, as they were usually conspicuous : the " good " and " average " trees were kept separate, while the " below average " and " poor " groups were united to form one class, " inferior." The five classes so formed are those used in Fig. 5, in which the relative growth data for the clones at each picket on Cheesman Field are shown.

The most evident fact is that really satisfactory trees, from the standpoint of growth, are few. As the basic data from which the scores were calculated are not given here it is desirable to point out that certain characters showed marked correlation : dense foliage with a stout trunk :

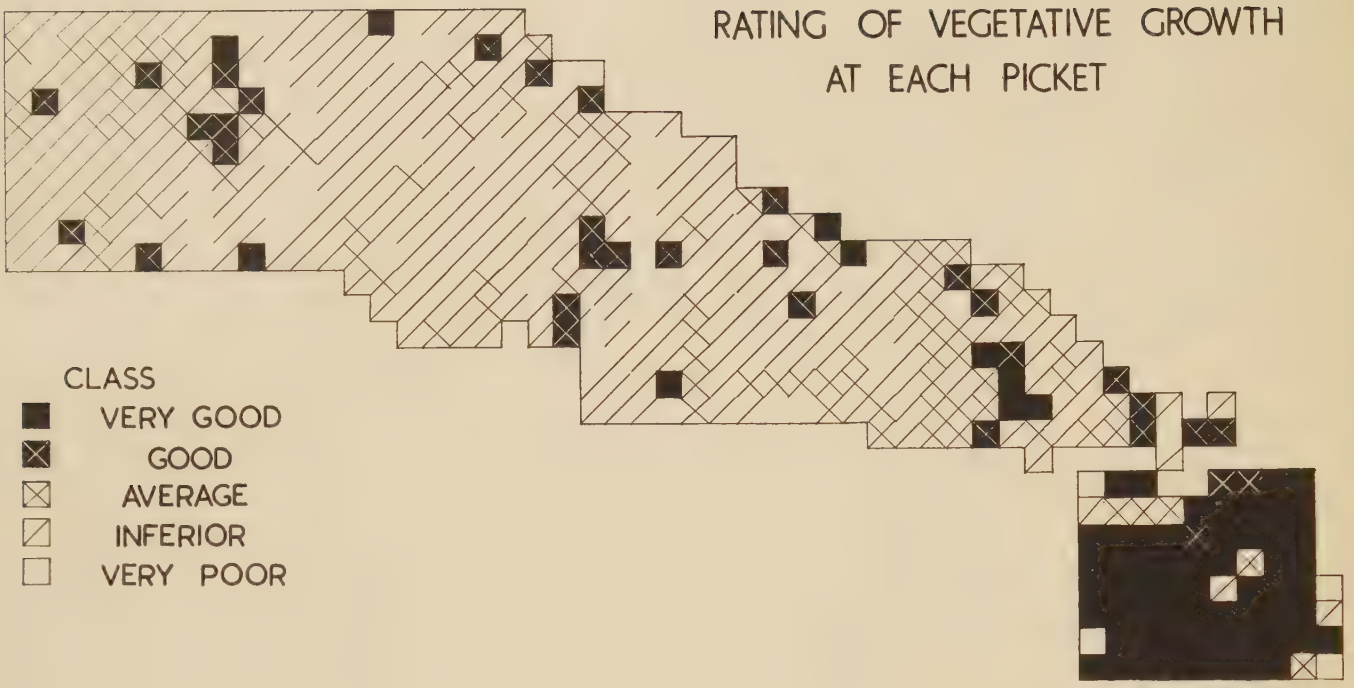

FIGURE 5
Plan of pickets on Cheesman Field, San Juan Estate, showing vegetative growth rating of each tree.

long terminal shoots with dense foliage ; excessive subdivision of apical branchlets (" stagheaded growth ") with sparse foliage, and often with a thin trunk. There is a negative correlation between growth habit classes and the cacao-thrips incidence classes shown in Fig. 3.

Abundance of Cacao-thrips in Relation to Yield of Cacao

The yield of each picket on Cheesman Field has been recorded for every cropping season since the field came into bearing. This work has been carried out by the Economics Department of the Imperial College of Tropical Agriculture, and it is from their records that the data embodied in Figs. 6-10 have been obtained. These figures show the yield-distribution in the first year of bearing (fourth year from planting) ; its distribution in an unusually " bad " year on this site (seventh year), and in the year which followed it (eighth year) ; Fig. 9 shows the distribution in an average year when the trees had come fully into bearing ; and, finally (Fig. 10) the yields of the last three cropping years (twelfth to fourteenth years) have been averaged to generalise recent cropping performance. The reasons for giving this series of figures are (1) to show yield-distribution in relation to time, (2) show the approximate range of variation from one year to another, (3) how such variation is related to the distribution pattern, and (4) show the topographical distribution of yield.

The yield-distribution pattern for the cropping season 1953-54, which concluded several months before the cacao-thrips outbreak of the wet season of 1954 began, was very closely similar, in the class rating of each tree, to the three-year average for 1952-54 (Fig. 10). The correlation between yield and growth habit is evident. The incidence of cacao-thrips is negatively correlated with yield in this field to a highly significant degree, and the regression graph is given in Fig. 11. The pattern of yield distribution, notwithstanding seasonal rises and falls, has remained unchanged for many years. If this pattern were the result of cacao-thrips attack affecting the crop, it is evident that cacao-thrips incidence must have been distributed in the same relative manner year after year : the insects must have been unable to colonise and to weaken the best trees. If the pattern of relative yield distribution has been determined by factors other than cacao-thrips attack, then the same factors determine the relative abundance of cacao-thrips at the appropriate season. Whichever interpretation is favoured the conclusion is inescapable that cacao-thrips, whether attracted or repelled, whether able to multiply or unable, are obligately dependent on an intrinsic factor in each tree of this field, and that this factor is largely independent of the genetic constitution of the tree.

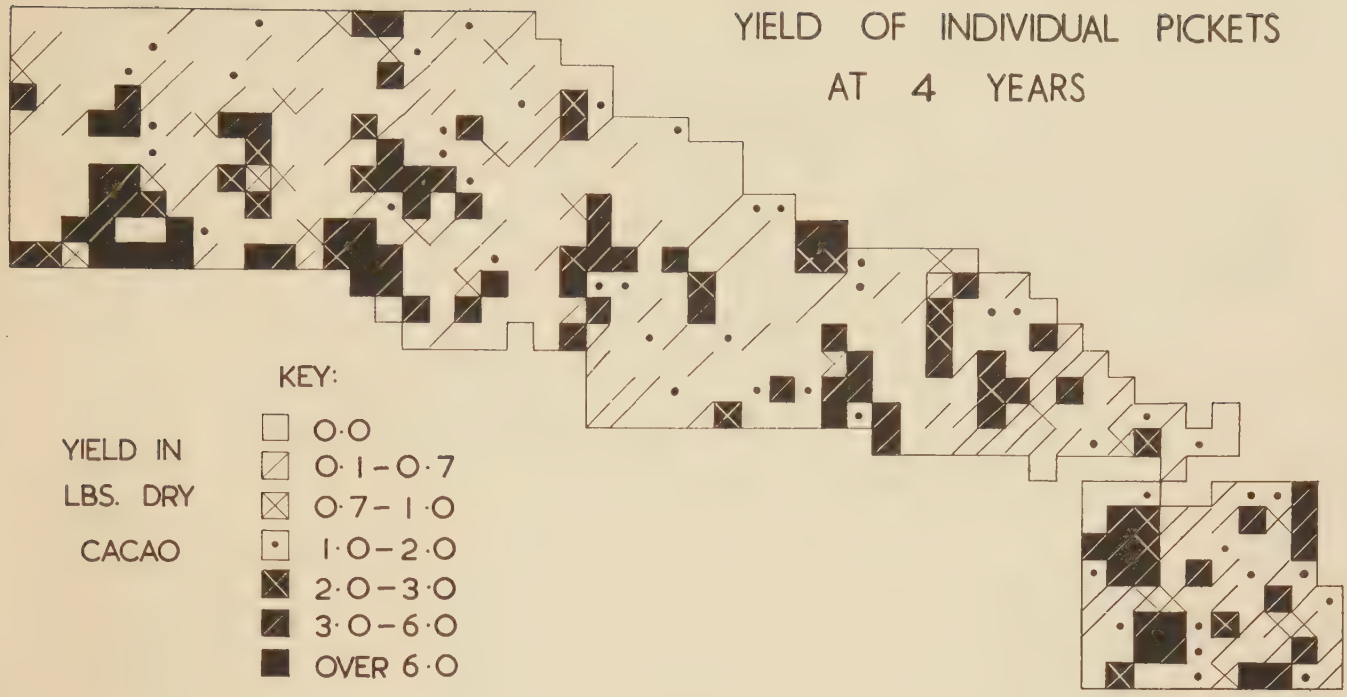

FIGURE 6
Plan of pickets on Cheesman Field, showing yield of each tree at four years.

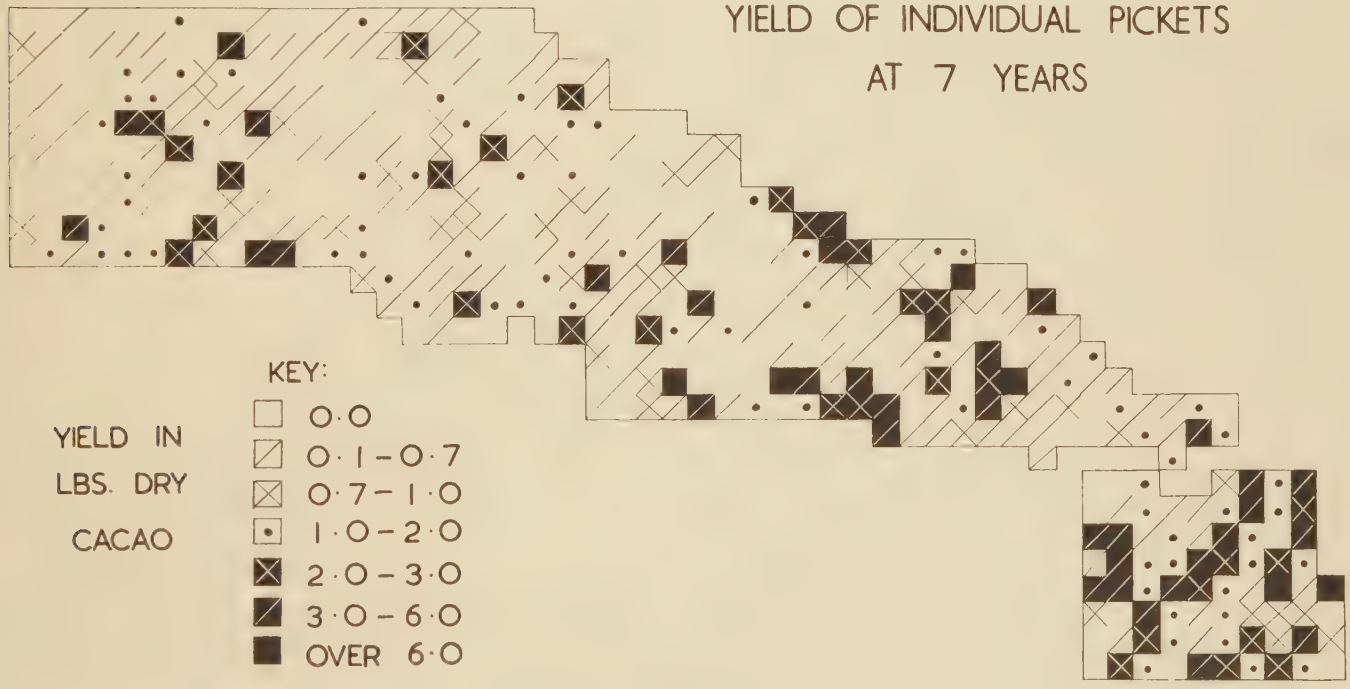

FIGURE 7
Plan of pickets on Cheesman Field, showing yield of each tree at seven years.

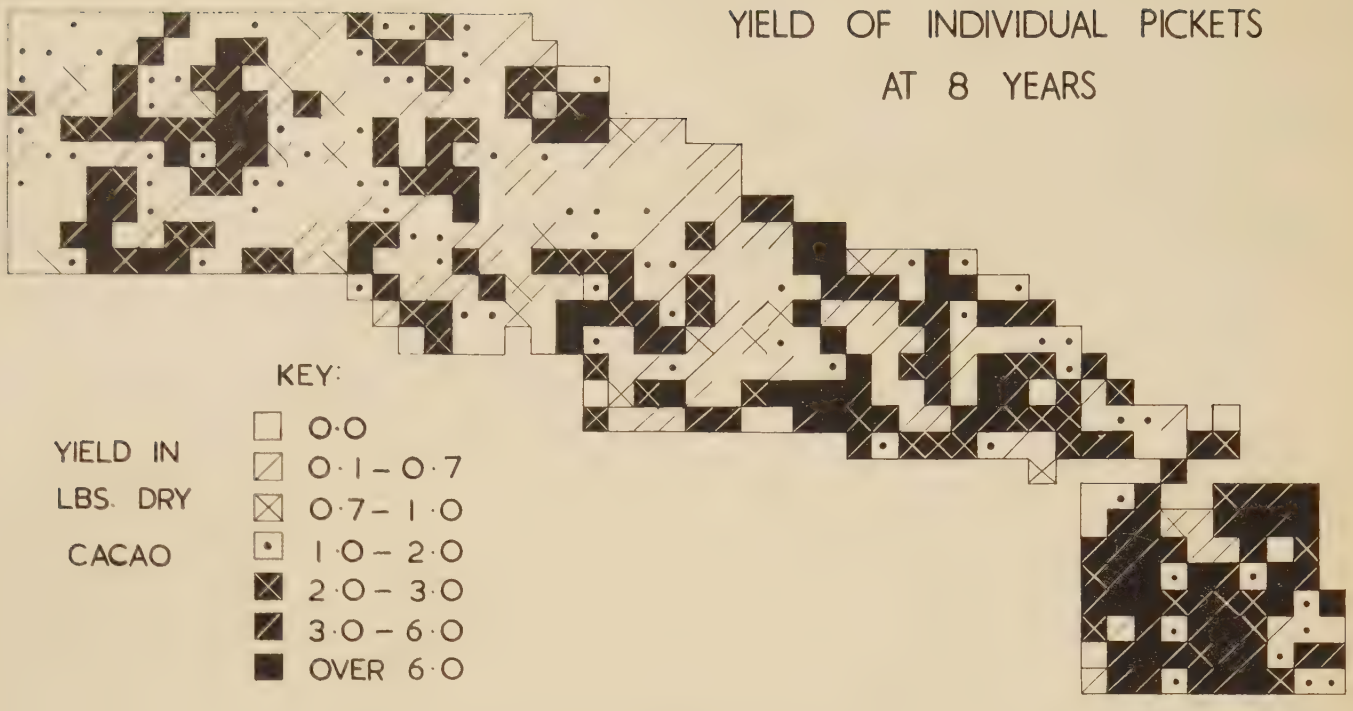

FIGURE 8
Plan of pickets on Cheesman Field, showing yield of each tree at eight years.

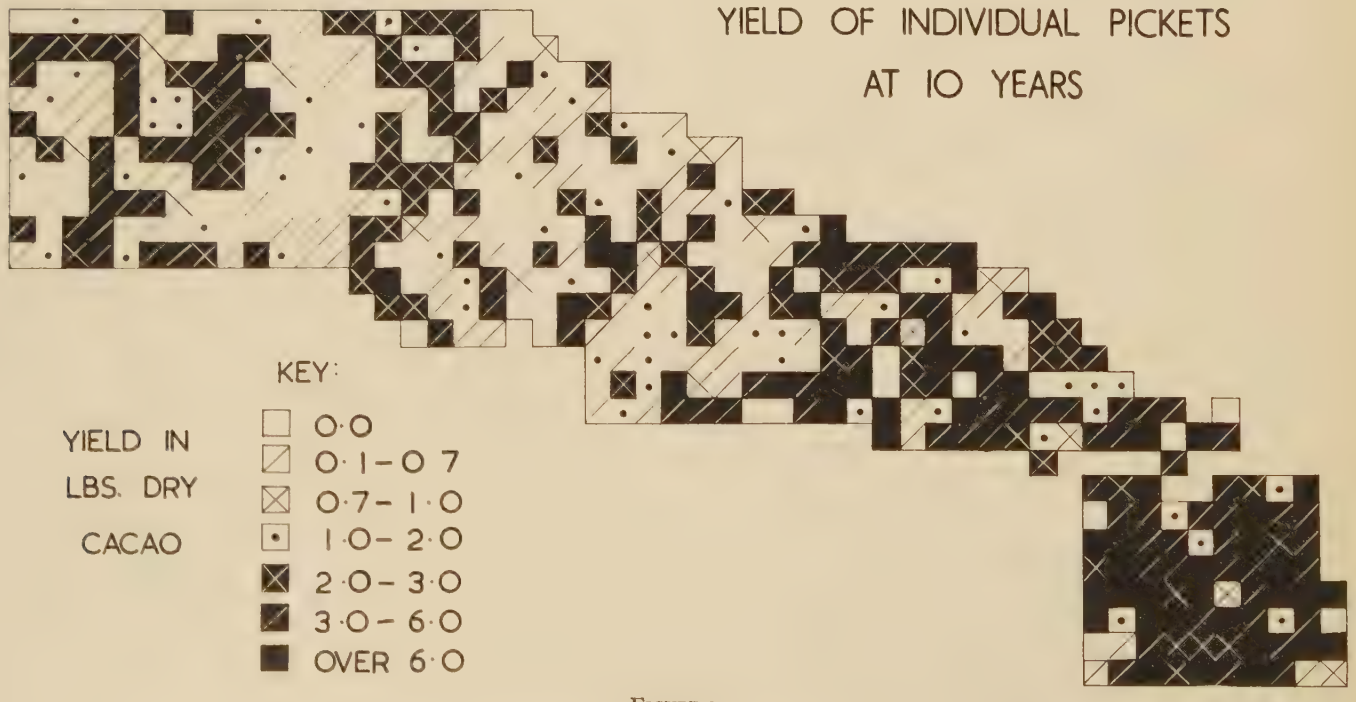

FIGURE 9
Plan of pickets on Cheesman Field, showing yield of each tree at ten years.

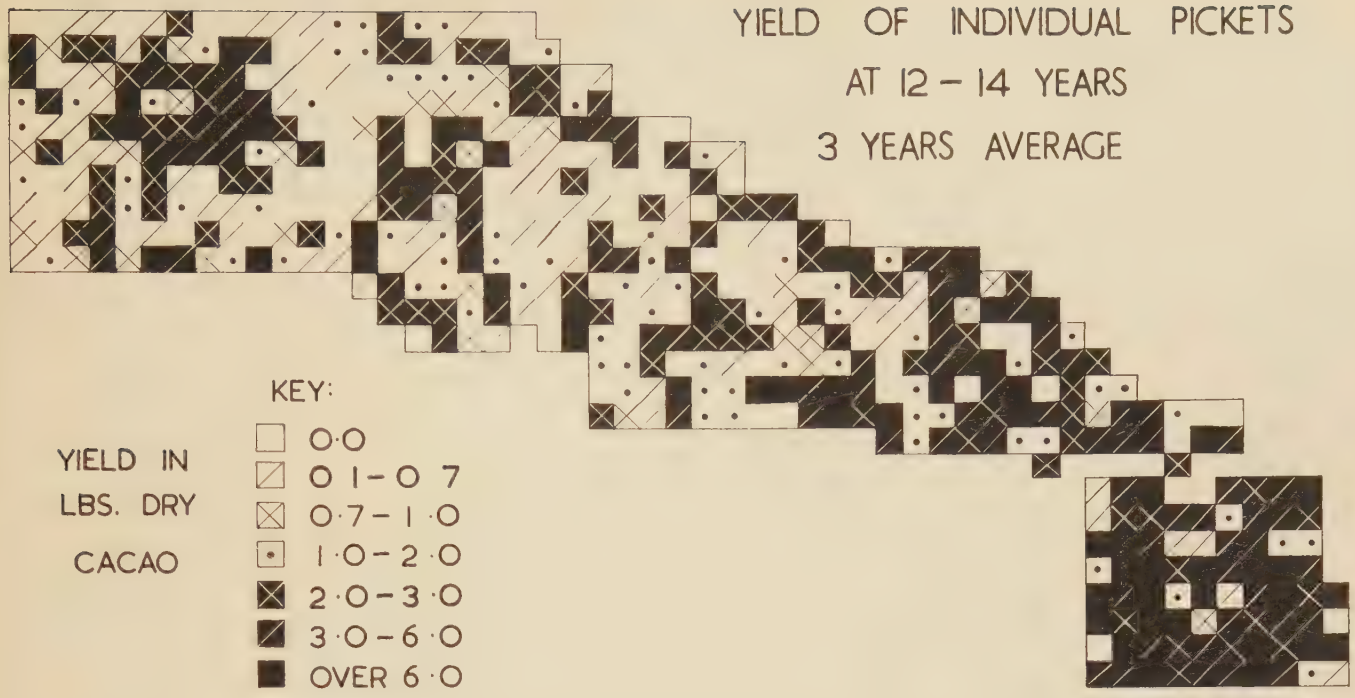

FIGURE 10

Plan of pickets on Cheesman Field, showing average yield per tree over three years, after twelve to fourteen years.

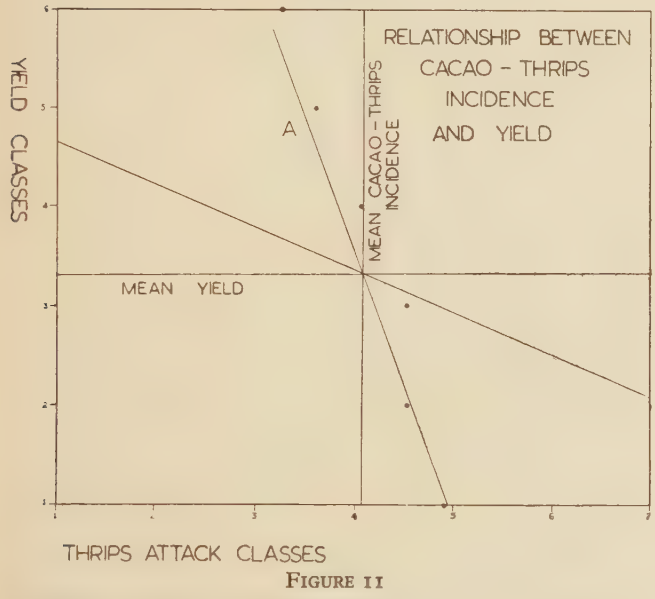

FIGURE 11

Regression graph showing intensity of cacao-thrips attack on yield (A) and yield on intensity of cacao-thrips attack.

Abundance of Cacao-thrips in Relation to Single Environmental Factors

(*a*) LIGHT

Most observers have recorded the greater prevalence of cacao-thrips in exposed than in shaded areas.

Other factors (unmeasured) are assumed to be equal and the difference is attributed to the effect of light, either on the insect itself (Reyne 1921, p. 201) or indirectly through some effect on the host plant (Darling 1942, p. 162).

The writer has seen, on a single site, in different years, examples of fully exposed seedling trees with a negligible incidence of cacao-thrips while shaded trees within a few yards were heavily infested : this relative position has been followed through an entire cropping season and has been found to remain unchanged. Furthermore, as mentioned above, it is common, if indeed not usual, for lightly shaded cacao-trees in or near November to be more heavily attacked in the lower parts of the canopy than in the topmost. It is clear that the generalised statement of the relationship between cacao-thrips incidence and light does not apply with the force of a law.

The facts, as at present known, do not support the view that the heavier incidence of cacao-thrips on exposed trees, when observed, is to be attributed *solely* to the effect of light, whether direct or indirect. They are compatible with an interpretation that the effect of *light* is positively, not, or even negatively correlated with intensity of cacao-thrips attack according to whether other factors are present or absent, and that the concomitant effects of insolation and air-movement on the water balance of the tree may, *in appropriate circumstances of water balance*, be positively correlated with heavier incidence of cacao-thrips.

(*b*) SOIL MOISTURE

In a survey of environmental features characteristic of sites with which satisfactory and poor growth of cacao trees respectively were habitually associated, McDonald (1932, p. 36) observed that a severe attack of cacao-thrips at the " bad " site was not parallelled by a corresponding outbreak at the good. From his data (which are best studied in the original) he was led to postulate a relationship between low *available* soil moisture and maximal increase of cacao-thrips. The probable significance of this relationship will be discussed below.

(*c*) Atmospheric Humidity

The normal range of atmospheric humidity in Trinidad cacao-fields is from 100% relative humidity to about 65% : on a few days in exceptionally dry weather it may fall to below 55%.

McDonald, referring to his own measurements, found that humidity was high at the time when he recorded an outbreak of cacao-thrips, and appears to have leaned towards the view that high humidity was prerequisite for cacao-thrips multiplication.

Pickles (1938) referring to two blocks of cacao trees " situated within a few yards of each other," wrote as follows :—

" One of these is normally subject to thrips attack while the other is rarely affected. It was found that, although the general thrips incidence was low, the plot susceptible to injury maintain(ed) a much higher thrips population than did the neighbouring plot. The indications are at the present time that the slightly affected plot has an appreciably drier atmosphere than the heavily affected one and that this fact is related to the rate of thrips increase."

It is to be remembered that atmospheric humidity is always very high at night in Trinidad, and differences between " dry " and " humid " become apparent only during the middle hours of the day. It is unlikely that the microclimate immediately adjoining the lower surface of a cacao-leaf is subject to very marked fluctuations, even when the leaf is fully exposed. Moreover, the present writer has once observed the multiplication of cacao-thrips in a glasshouse in Trinidad where diurnal relative humidity commonly fell close to 40%, a level never recorded in established cacao fields.

There is no direct evidence that low diurnal humidity, within the range normal in cacao fields, is inimical to the development of cacao-thrips : there is no evidence at all that it is immediately beneficial to the cacao trees.

No significance need be attached to the indications which Pickles records, since relevant factors were eliminated by assuming that the close proximity of the two plots ensured that all other factors were practically equal. The example of Cheesman Field illustrated in the figures clearly shows the inadmissibility of such an assumption.

(*d*) Nutrient Elements in the Soil

Nitrogen and Potash

McDonald (1933, p. xi) found that samples of cacao leaves infested with cacao-thrips when compared with leaves that were free from infestation showed a higher ratio of nitrogen to potash. Stephenson (1938) carried out feeding tests in petri dishes using discs cut from leaves which had been taken from potash-treated plants and non-treated plants respectively, and found a significant negative correlation between potash content of the leaf and acceptability to cacao-thrips.

On the Cacao Shade and Fertiliser Experiment at the Imperial College of Tropical Agriculture a comparison was made between the number of trees infested with thrips on plots which had received nitrogen and those which had not. A similar comparison was made between plots which had been treated with potash and those which had not. The cacao-thrips attack was light and the total number of trees infested was low, but the data showed that significantly ($P=0.02$) more trees were infested on the plots which had received nitrogen than on the non-treated plots. No difference was established in the comparison between plots which had or had not received potash.

At La Reunion Section of the Central Experiment Station of the Department of Agriculture leaves infested with cacao-thrips were collected on a shaded watershoot together with thrips-free leaves of young but mature foliage higher on the same tree, and the samples were compared in respect of nitrogen partition. The results are as follows (Table III).

Table III

Nitrogen partition in a watershoot and fan branch from the same tree.

	Leaves from Watershoot	Leaves from Fan branch
% moisture	59.2	60.2
Ethanol insoluble matter as % dry weight	76.3	77.2
Total nitrogen as % dry weight ...	2.18	2.28
Ethanol soluble N as % dry weight	0.29	0.48
α-amino nitrogen as % dry weight	0.059	0.053
Insoluble nitrogen as % dry weight	1.89	1.80
α-amino nitrogen derived from insoluble N as % dry weight ...	1.42	1.07

A paper chromatogram in which extracts from the two samples have been developed to show ninhydrin-reacting compounds is reproduced in Fig. 12. A pronounced difference was noted in the amount of asparagine present, the greater amount being in the extract from leaves of the watershoot. Leaves from the fan branch had less chlorophyll and a markedly higher polyphenol content than those from the watershoot.

Iron, manganese and other minor elements

Maskell, Evans and Murray (1953, pp. 58, 59) have described the foliar symptoms of iron and manganese deficiency in cacao. Deficiency of available iron is commonly evident in cacao leaves in the field towards the end of the wet season, and may become strikingly so on calcareous soils. The soil of Cheesman Field in most places overlies limestone, and symptoms of available iron deficiency in varying degree are visible at most pickets. An analysis of leaf samples from this field showed the following composition.

Writing of a site on the Brasso Clay, Evans (1953, p. 42) records that " a complete series of (leaf) injections on clonal cacao . . . gave responses to iron, manganese, copper, magnesium and cobalt. Of these iron was the dominant deficient element, although responses to the other elements were perfectly clear." This site not only had a history of retarded growth, but also of recurrent and heavy cacao-thrips incidence.

Cacao-thrips attack on young trees growing at the Imperial College of Tropical Agriculture has been negligible, and for the most part quite absent, at least for the past five years, and no example has been found of a heavily-infested leaf on the Cacao Shade and Fertiliser Experiment since its inception. Evans (1953, p. 45) has published comparative data for the relative abundance of potash, phosphate, magnesium, aluminium, calcium, chlorine, iron, manganese, copper, zinc and boron in cacao leaves from a site close to Cheesman Field and from vigorous cacao at the Imperial College of Tropical Agri-

TABLE IV

Composition of cacao foliage from Cheesman Field and adjacent site on a basis of oven-dry matter

% Ash	% P_2O_5	% K_2O	% CaO	p.p.m. Fe_2O_3	Flushing period	Colour	Clone
9.16	0.300	2.62	1.37	100	late October	Chlorotic*	ICS 94
9.48	0.263	2.63	1.35	92.9	late October		
13.09	0.274	2.25	2.69	136	late October		
14.89	0.230	1.88	3.88	122	early September	Chlorotic*	
14.16	0.226	1.25	4.00	250	June-July	Dark green	
7.87	0.547	2.67	0.95	186	January	Pale green	ICS 95
8.23	1.068	2.75	1.07	136	January	Pale green	
11.21	0.521	1.69	3.07	179	September	Pale green	
7.21	0.531	2.95	0.54	136	January	Immature hue	ICS 95
12.64	0.522	1.73	2.81	129	January	Pale green	
14.00	0.335	1.27	4.23	193	September	Green	
8.26	0.944	2.75	0.78	119	February	Pale green	ICS 84
8.17	0.439	3.01	1.25	169	February	Pale green	

* Leaves of similar age on this tree gave a response to a foliar injection with acidified ferrous sulphate solution.

FIGURE 12

Paper chromatogram showing amino-acids from watershoot leaves (centre column) and from a fan branch on the same tree (left-hand column).

culture. These data show that leaves from the I.C.T.A. samples were much richer in iron, manganese, copper and zinc than the San Juan samples, and poorer in boron, potash and phosphate.

In the latter part of the wet season a strong response has been obtained at Cheesman Field on chlorotic leaves of the September and January flushing periods to an injection with acidified ferrous sulphate solution. Towards the end of the dry season such chlorotic leaves at this site rapidly become green, after which a response, if visible at all, is faint. Such a striking degree of seasonal variation is, of course, not indicative simply of the relative availability of one nutrient.

Discussion of Data

The facts presented above show that cacao-thrips attack occurs on leaves of the later wet-season flushes, and reaches its peak shortly after they have hardened. Leaves of the flush which follows the rain showers which mark the onset of the wet season are free from infestation and only become infested, if at all, rather late in their lives. Infestation of a particular flush is of about a month's duration.

The comparatively slow increase of cacao-thrips on leaves of the August flush during the main outbreak of October-November, and the observed relative immunity of *old* leaves from reinfestation, indicates that there is an upper physiological-age limit to the period over which a leaf is suitable for colonisation. At the other extreme of age, as Reyne has recorded (Reyne 1921, p. 202), and as has repeatedly been observed in the laboratory, very young flaccid leaf-tissue of cacao is not accepted as food by cacao-thrips. In the absence of interference by predators the curve of cacao-thrips abundance would be expected to follow that for ageing of the leaf, where ageing implies increasing export of nitrogenous compounds. In the field, however, parasitic fungi and predators are always present and accelerate the rate of population decline. The persistence of the last members of a large cacao-thrips population in sheltered enclaves (or under the canopy of small webs) suggests that such places afford a protection that is seriously needed.

The association of by far the greatest part of the cacao-thrips population with hardened leaves of the flush which preceded its multiplication (excepting the first flush of the

rainy season) accounts for the variations, within a few weeks, of the peaks of maximum cacao-thrips abundance from one year to another. Multiplication of cacao-thrips depends on the prior flushing of its host, when the host is cacao, and this in turn is determined, as far as is known, largely by meteorological conditions (Humphries 1944, p. 30), which are never quite the same from one year to another.

The absence of cacao-thrips, in most fields, from leaves produced in the first flush of growth of the rainy season, the negligible incidence of cacao-thrips on trees known to be vigorous (as defined by growth habit and yield history), the significantly less frequent occurrence on, and significantly lower infestation of, vigorous ICS clones such as ICS 95 in comparison with " delicate " clones such as ICS 1, and the relatively higher incidence of cacao-thrips on leaves with a high nitrogen/potash ratio or unbalanced in regard to certain minor metallic nutrient elements, appear to be explicable only by assuming that the physiological condition of the cacao tree determines the presence or absence of cacao-thrips, and to some extent their degree of abundance on the foliage. The data do not support the view that the observed differences between vigorous and unthrifty trees are to be attributed to the relative amount of damage inflicted by cacao-thrips.

It is widely believed that cacao-thrips is a primary pest of cacao, and the course of events by which its reputation has been earned is pictured as follows. Adult cacao-thrips migrate from other host plants on to cacao and lay eggs. The resulting progeny feed on the leaves and cause so much damage that the leaves are shed. A new flush of growth is put forth, and this shares the same fate as its predecessor. The process is repeated at intervals and the reserve of nutrients in the tree is steadily depleted by the frequent replacement of lost foliage. If the decline is not arrested the tree ultimately dies. Artificial defoliation of cacao trees at intervals has been found to lead to this result (Reyne, 1921, p. 205), and it has been assumed that cacao-thrips produces a defoliation which is comparable in every way.

Thrips (Thysanoptera) in general feed on rapidly differentiating tissues, as in terminal buds or flower-buds, or in the region of the proliferating tissues at the base of a flower ; a few are predaceous on insects (including other thrips) ; and some, like cacao-thrips on cacao, are able to feed and multiply only on mature foliage. It is well established that cacao-thrips will not feed on foliage that is too young, or, in fact, much younger than " mature." Senescent foliage is also unacceptable, even though it may have been attacked at an earlier stage.

As is evident from the résumé of the life history at the beginning of this article, a generation of cacao-thrips occupies about twenty-six days. At the time of the first flush of growth following the onset of the rainy season, the cacao-thrips population is at its annual minimum : nevertheless, as Callan's data show, it is already present in cacao fields. Moreover, the complex of predators which feed on cacao-thrips (if that part of it which Callan studied is typical), is also at its lowest, and cannot increase until food, in the form of cacao-thrips and other insects, has become readily available. It is probable that cacao-thrips is given a generation in which it is free to exploit the newly-produced leaves as they harden without sustaining the heavy numerical losses that predators can inflict. In this connection it is worth recalling that in October, on the hardened August-September flush, cacao-thrips build up in numbers to their annual peak in spite of such persecution, which, according to Callan's data, is by then formidable.

Why, then, do they fail to colonise leaves of the first wet-season flush ? The failure is not absolute, in the sense that it occurs on all sites in all years : De Verteuil (1933, p. 27) records that " thrips began to appear at the end of June " at Marper Cacao Experiment Station in an area of inferior soil types, and in a typical " thrips pocket " similar behaviour at this time of year may not uncommonly be observed. In seeking an answer to this it is necessary to answer further questions. How do leaves of the first wet season flush differ from those of subsequent flushes ? How do the leaves of any one clone, showing only the lightest infestation of cacao-thrips at one picket, differ from leaves of the same flushing period on the same clone, at another picket in the same field and at the same time, which are heavily infested with cacao-thrips ? How, on a single tree, do leaves infested with cacao-thrips on a watershoot near the base of the tree differ from leaves in the uppermost parts of the canopy which, though of acceptable age, are free from infestation ?

Such questions, which preclude the possibility of appeal to differences in genetic constitution of the contrasted tissues, and of which one (the first) refers to a seasonal change, suggest that the answer to each is to be found in differences in foliar constitution which have been induced by the immediate environment.

It has been mentioned above that a sample of watershoot leaves was found to contain appreciably more asparagine than exposed leaves from the same tree. No significance is attached here to this compound : the significant fact is that nitrogen metabolism in the lower leaves is quantitatively different from that in the upper. It is quite probable that other soluble nitrogenous compounds, undetected by the reagent used, may be available in greater concentration in the lower leaves than the upper. A positive correlation, significant on a normal site, has been established between susceptibility to infestation by cacao-thrips and total nitrogen status of the leaf. A positive correlation has also been established between incidence of cacao-thrips and nitrogen/potash ratio of the leaf. The latter relationship has been discussed by Hardy (1937, p. 20) : he drew attention to the physiological role of potash as a stabilising agent for protein, and pointed out that as such its absolute concentration in the leaf was of less importance than its relative abundance in relation to total nitrogen. Where potash is relatively deficient leaf protein may be more prone to extensive breakdown in the presence of hydrolytic agents.

If this mechanism is considered to be relevant to the problem of cacao-thrips abundance, then it is necessary to assume that a rapid increase in a cacao-thrips population can occur only where the insect can obtain soluble nitrogen *in abundance*. In short, that the factor is the *rate of delivery* of the soluble nitrogenous compounds to the apex of the feeding stylets of the insect, and that this is determined by the rate and extent of breakdown of cellular leaf-tissue in the vicinity of each feeding incision. The size of a single feeding incision and the amount of saliva injected is regarded as constant, while the degree of reaction by the leaf-tissues is variable.

It remains to be seen whether the rest of the available data fit this assumption.

Abundance of cacao-thrips has been found to be high on leaves of appropriate age which are deficient in available

iron, manganese, zinc and copper. It is known that an adequate supply of iron is necessary for synthesis of chlorophyll and for its preservation ; zinc is regarded as an essential agent in the activation of growth promoting hormone (Skoog, 1940). The work of Maskell, Evans and Murray (1953) has shown that each of these elements, in addition to discharging such specific functions as those just mentioned, exercises an all-pervading influence on the health and vigour of the plant. The responses which were found to foliar injection were visible proof that the mechanism of chlorophyll synthesis or stabilisation had been retarded by deficiency in an available form of the elements injected. It is reasonable to expect a correspondingly adverse effect on the constructive process by which soluble nitrogenous compounds are converted into protein, and on the stabilising mechanism which retards its normal rate of breakdown.

In Trinidad, as the dry season progresses, the moisture content of the soil falls (Humphries, 1944, p. 28) and soil nitrification proceeds actively. In the oxidising conditions which prevail in the drying and aerated soil, iron, and presumably other minor metallic nutrients, are present in a form available to the plant. At this time of year, probably on account of the low availability of moisture, growth of cacao trees is relatively slow. With the onset of the wet season nutrient uptake by the tree is accelerated, in conditions where soil nutrients are available to their maximum degree, and a period of intensive, or " boom," growth ensues. On large tracts of the cacao-growing areas of Trinidad this brief period is the only time in the year when relatively unretarded growth is possible.

The first leaves produced at this time are unlikely to suffer from nutrient deficiency, except on soils where a major nutrient such as potash is always deficient, or where drainage is always impeded. Moreover, as metals such as iron and zinc do not appear to be translocated to any important extent from one leaf to another, a loss of these is not likely to occur later in the life of such leaves. Potash and nitrogen are mobile, and are progressively withdrawn as the leaf grows older. Where both are withdrawn *pari passu*, the leaf, though past the peak of tissue constructional activities, does not become seriously unbalanced in respect of cellular nutrition, and the relationship between rate of protein synthesis and rate of hydrolysis changes only slowly in favour of the latter as the months pass (Fennah, 1954, p. 48). If, from the standpoint of protein metabolism, aging of the leaf operates in favour of cacao-thrips, it does not do so in other respects. Old leaves have the least moisture content of all ; their cell-walls are toughened and they have lost, by withdrawal, a substantial part of their nitrogen. These changes may be deemed sufficient to account for the immunity of old leaves to attack.

On a rather impoverished soil, or at a site where the soil is rather less favoured by the ameliorating effects of dry weather, the first leaves of the wet-season flush may be sufficiently well provided with nutrients at the outset, but may become depleted of potash (on account of its translocation to developing fruit) soon after the " boom " period of growth is over. If nitrogen supply is not limiting then a condition of relative unbalance could arise which would be suitable, though not ideally so, for cacao-thrips. Such leaves, unattacked at first, might be infested later for a rather short period before they reached physiological senescence. Leaves of this type can be observed in the field in September, in environmental conditions similar to those postulated above.

Finally, on a site where waterlogging occurs in the wet season, and the soil rarely dries out in the dry season, a state of minor element deficiency or unbalance may be semi-permanently present in the cacao trees, and only be relieved in an unusually dry year. The first wet season flush, on trees such as these, will be " unbalanced " on account of the induced metal deficiencies, and as soon as leaves of the flush begin to harden, with their relatively high total nitrogen content and their relatively enfeebled protein-synthetic or protein-stabilising mechanisms, they will offer suitable pabulum for cacao-thrips and become infested. Such a situation as this probably occurred at Marper Cacao Experiment Station when De Verteuil (1933, p. 27) recorded an upsurge of cacao-thrips soon after June, as drainage in this area was later considered by Pound to be defective.

The environmental vicissitudes which affect the metabolic history of the first wet-season flush of leaves have just been discussed as if they fall into three distinct classes, whereas the gradation from one condition to another is very smooth. Using the three-class convention, however, it can be stated that the total of first wet-season flush leaves is divided unequally between them, and that the second is probably the commonest condition found followed by the first and, at some remove, by the third.

It is now necessary to examine the environmental conditions which prevail about September, when a second major flush is usually produced.

The frequent showers of the early wet season rapidly and substantially increase soil moisture. This, after reaching an early peak (Humphries, 1944, p. 28) declines more or less slowly according to soil-type, with minor fluctuations imposed by the distribution of showers (McDonald, 1932, Figs. 1 and 2). Heavy clay soils, once thoroughly saturated, form an unsuitable medium for optimal growth of cacao, and in many areas remain as such until the onset of the following dry season. Where the soil reaction in the surface layers is alkaline, or nearly neutral, the presence of too much water (or the absence of sufficient air) induces in the leaf deficiency of certain minor elements, such as iron in an available form. Such deficiency, according to its degree of severity, retards growth and reduces the longevity of the leaves. In all cases where specific nutrients are unavailable in the leaf, a direct retardation of protein synthesis, and promotion of protein hydrolysis, is to be expected according to the results obtained by Maskell, Evans and Murray.

Such deficiencies, usually multiple, are induced, in all but a few cacao-growing areas, on leaves produced after the middle of the wet season, and their symptoms usually appear on leaves of the September flush. As mentioned above, deficiencies of available forms of minor metallic elements cannot be made good by translocation from older leaves which are not deficient. The development of a large population of cacao-thrips on such leaves is to be expected.

According to the available data (Humphries, 1944, p. 28) soil moisture, even at a site which, by Trinidad standards, is relatively well drained, may not fall more than half way towards its dry-season minimum before the end of February. On poorly drained soil the rate of fall, which implies the rate of increase in soil aeration, is proportionately slower. This means that leaves of the January-February flushing period are produced in conditions not basically different from those prevailing at the time of the September flush. It is, therefore, to be expected that

these will share a similar fate, and provide a breeding site for cacao-thrips. It is the attack on this flush which is usually considered as the " dry-season " attack of cacao-thrips. It is most probably the persistent effects of wet-season soil conditions which give rise to it, though, at exposed sites, enhanced water-stress may be added to the unfavourable conditions with which the tree is beset.

It has been shown that the distribution of vigorous and relatively poor trees on Cheesman Field has remained stable since the plants came into bearing. This pattern has been determined by climatic factors operating in relation to local soil differences,* as is evident from the results of leaf analyses and of a visual survey of the distribution of nutrient-deficient foliage. It is evident from Fig. 5 that the operative factors have been sufficiently potent to retard growth of all but one or two of the hundred ICS clones. (The differences evident in Fig. 5 could have been demonstrated in the yield data if yields above 6 lb. of dry cacao per tree had been further classified.) It is also evident that the distribution of the weight of cacao-thrips incidence is correlated with the pattern of yield and vegetative growth. It can be seen that the distribution of cacao-thrips is not, in its main features, determined by factors peculiar to individual clones. The clones in each of the five blocks are planted in the same sequence, from 1 to 100. If the incidence of cacao-thrips were correlated with intrinsic factors in the host plant which were determined principally by genetic constitution (such as the presence of attractant or repellent substances), then the pattern of cacao-thrips incidence, or a very large part of it, would be repeated unchanged in each block of clones.

Even the most vigorous of this series of ICS clones is not absolutely resistant to cacao-thrips, and its performance on Cheesman Field is only broadly indicative of what may be expected elsewhere. The clone ICS 1, which at all pickets has fared badly, has remained free from cacao-thrips attack for years at other sites (as at I.C.T.A. and parts of River Estate) on soils of different structure. Such behaviour shows that susceptibility to attack is not normally determined by constitutional factors which are present in any clone at all times and in all places.

It has been remarked above that cacao-thrips cannot thrive on the young foliage of a flush while it is still flaccid. No satisfactory explanation has ever been advanced to account for this, although the fact has been recognised for many years. Two possible explanations fit the facts, and it is possible that both, in varying degrees, are correct. Firstly, the moisture content of a flaccid flush leaf forms about 80% of the total weight ; in a hardened flush it forms almost 50% (Fennah, 1953). It is conceivable that the cell solutes are too dilute in very young tissues to provide adequate nutriment for cacao-thrips. Alternatively, it is known that anabolic, or " constructive," processes are greatly in the ascendant in flushing leaves at this stage, and it is conceivable that the stabilising mechanism offers considerable resistance to protein-hydrolytic agents (such as salivary protease). In such an event it would be likely that the only soluble nitrogenous compounds available to the insect would be those derived from the solutes of only a few cells traversed by the feeding stylets and from dead protoplasm in immediate contact with the stylets. In short, the nutrients, though possibly of suitable composition, may be obtainable at any one puncture only in very small amount, and, upon withdrawal, not replenished by " seepage," from other cells, as the surrounding cells are able to " neutralise " the enzymatic action of the injected saliva.

The latter suggestion receives a little support from an observation made by the writer. An incipient colony of cacao-thrips, comprising three nymphs, was found on a full-sized but *not fully hardened* leaf of a February flush at a " bad " site. It was obvious that the leaf was chlorotic, and there was reason to suspect that its cellular metabolism was " precocious," and comparable, in so far as comparison is possible, with that of a normal leaf of greater actual age. This interpretation is admittedly an extension to a milder case of an explanation which can be applied with more confidence to an extreme. Reference must be made again to the example of premature ageing seen in flushing leaves which are seriously deficient in available iron, or in the available forms of a group of minor metallic nutrients. Such leaves fail to expand beyond half of normal size, and harden even before they have lost their juvenile coloration (cf. Maskell, Evans and Murray, 1953, p. 58, Fig. IXb). They are physiologically much older than they appear, and are destined to be short-lived. As has repeatedly been observed, they are subject to infestation by cacao-thrips.

Notwithstanding the emphasis placed by Reyne (1921, p. 201) on the role of light in " focusing " cacao-thrips attack (by attracting adults to the most brightly illuminated trees), there can be little doubt that results ascribed to the influence of light are partly produced by associated factors, such as insolation and air movement. Darling (1942, p. 152) rejected Reyne's explanation on the ground that the ratio between nymphs and adults counted on fifty shaded and unshaded sites gave no indication that adults were relatively more numerous at, and, therefore, must have migrated to, the more brightly illuminated spots.

The reports of Evans and Murray (1953) and Murray (1953) show that the effect of light on the foliar constitution of the cacao leaf is modified by the nutrient status of the plant. Where an adequate supply of nutrients is available, and soil moisture is optimal, leaves exposed even to full sunlight are not more infested by cacao-thrips than shaded leaves. Indeed, in such circumstances they are not at all infested. Where nitrogen is deficient but soil moisture is optimal, the most exposed leaves show the most marked symptoms of nitrogen deficiency. This deficiency, considered by itself, is unfavourable to the multiplication of cacao-thrips, but in so far as it contributes to a condition of nutrient unbalance, predisposing the leaf to breakdown, it is favourable. Where soil moisture and soil pH are such that iron is rendered largely unavailable in the leaf, the condition may be accentuated under high light intensity (Evans, 1953, p. 43). Lack of available iron in the leaf is associated with cacao-thrips attack. It is possible that unavailability of zinc and other minor metallic nutrients is also aggravated by insolation. The relationship between light and potash content of the leaf is similar to that for nitrogen. The nitrogen/potash ratio is, therefore, not necessarily affected by light. Where, as described above, cacao trees under tall light immortelle shade were observed, in the latter half of the wet season, to be infested with cacao-thrips in the lower and more shaded part of the canopy, and free, or relatively free, from infestation on the topmost exposed leaves, it is likely that the difference is to be attributed to the effect of light acting in conjunction with a complex of nutrient deficiencies. The nitrogen-

* These are at present being studied by the Soil Chemistry Section (Cacao Research).

partition data reveal clear differences in nitrogen metabolism between exposed and shaded leaves in the prevailing conditions.

The effect of insolation and air movement on cacao leaves is to accelerate transpiration of moisture. The degree to which such acceleration results in a deficit is related to the rate of water uptake and transport. This in turn depends on the " availability " of soil moisture. Conditions of drought or of impeded drainage result in reduced availability of soil moisture. The physiological effects of high water stress on the leaf include retardation of protein synthesis. McDonald (1931, p. 36) regarded a diminution in leaf moisture (resulting from excessive diurnal transpiration) as favourable to cacao-thrips attack.

An unduly high level of soil moisture, if protracted, under conditions of stagnation at an appropriate pH, results in the development of foliar chlorosis. It also results in retarded growth and reduction in the hormonal superiority of apical buds. The latter leads in time to the development of a system of frequently forked branches, each of which is thin and short : the outermost branchlets may be not much longer than the petiole of a normal healthy leaf. On account of their general appearance such branches are often termed " stagheaded." Such growth indicates that the trees are physiologically predisposed to infestation by cacao-thrips.

The opposite phenomenon of seriously deficient soil moisture may occur on soils of light texture, or on very exposed sites, late in the dry season. Before such drought conditions have reached their peak a considerable period has usually elapsed since the last flush of leaf growth, and all the foliage is past its optimum age for supporting cacao-thrips.

Hardy, reviewing McDonald's work (1937, p. 22), pointed out that incidence of cacao-thrips attack in Trinidad seems to be connected with incipient drying of leaves following diminution in available soil moisture during periods of high atmospheric humidity. In McDonald's data for soil moisture (1933, Figs. 1 and 2) the time of a cacao-thrips attack is indicated by a vertical arrow above a relatively precise date, implying that onset of the attack was extremely sudden. The date indicated happened to follow closely upon a sudden (and relatively minor) fall in soil moisture. This interpretation, in which the diminution in available soil moisture is considered to be related to the small " notch " in the soil moisture curve, fails to take into account the normal annual development of the cacao-thrips population which rises to its maximum, declines, then rises and falls again *irrespective of minor fluctuations* in the moisture content of the soil. The rapid development of a cacao-thrips population on any given tree is related to the presence of a hardened flush : if it could be shown that flushing is related to minor fluctuations in soil moisture McDonald's interpretation would be valid. So far, however, no such correlation has been found (Humphries, 1944, p. 28). The concomitant presence of high atmospheric humidity postulated by McDonald as requisite for multiplication of cacao-thrips is apparently unnecessary. Cacao-thrips can multiply at lower diurnal humidities than ever occur in Trinidad cacao fields, while high humidity in itself is in no way deleterious to cacao.

It remains to consider the relationship between cacao-thrips attack and the development of cacao pods.

Even in fields where foliar infestation is heavy, extensive disfigurement of cacao pods is not necessarily common, though, as the actual number of pods is usually high, examples may readily be found. Heavy infestation of pods does not occur where foliar infestation has remained negligible.

Humphries (1944, pp. 23-27) has followed certain of the changes which occur during the development of a cacao pod. He recognised a developmental phase of about seventy-five days, and a maturation phase of about a hundred days. It is in the third period of the second phase, when the pods are more than 140 days old, that cacao-thrips attack becomes evident. This is the ripening phase. It has been shown that at this time fructose and sucrose increase to their maximum while the moisture content of the wall remains level. No information is available about nitrogen partition in the skin of the pod at this time, but it is probably true that the changes are comparable to those which occur in a leaf as it grows older, and that soluble nitrogen increases. The timing of cacao-thrips multiplication, out of the 170-day period available, would seem to be determined by changes that occur during the maturation phase of the pod.

It is now necessary to see how far the general picture given above, in which (*a*) the annual curve of development of the cacao-thrips population, (*b*) the particular cacao trees susceptible to attack, and (*c*) the specific leaves of cacao which are infested at any given moment are considered to be determined primarily and invariably by the status of nutrients in the leaf and of nutrient reserves in the tree, can accommodate facts which have guided other workers to the opposite conclusion, namely, that it is cacao-thrips attack which is the primary cause of the damage which leads to depletion of nutrient reserves in the tree.

The most complete presentation of this viewpoint is that of Reyne. Although it refers to conditions in Surinam, the arguments are based on data which can be paralleled in Trinidad. The following points are quoted from his summary in English (Reyne, 1921, pp. 195-214.)

" *For many years in Surinam great loss of trees has been experienced. . . . This loss was looked upon as almost wholly a consequence of the witchbroom disease. But . . . never cacao trees die as a consequence of witchbroom. . . . Besides canker (Phytophthora) and borers (Steirastoma) . . . no other diseases or pests are known here that can kill cacao trees, so that this loss must probably be largely ascribed to thrips.*"

This conclusion is unwarranted, as no cognizance has been taken of the possible effect of adverse environmental conditions.

(*a*) *Healthy and vigorous cacao trees are soon exhausted after repeated artificial defoliation . . . , showing after each defoliation smaller and fewer leaves and soon also dieback and dying of buds in all stages of development, as seen in trees severely damaged by thrips.*

(*b*) *Thrips-damaged leaves are soon cast and usually do not grow older than 3-4 months (often no more than 1-2 months) whilst healthy leaves attain 6-8 months and more. . . .*

(*c*) . . . *Only twigs that are emptied* [of reserves] " *die back.*"

At the Imperial College of Tropical Agriculture cacao trees have been grown in markedly suboptimal conditions of nutrient supply, accompanied by under-watering or excessive over-watering. The overall rate of evaporation at one site (a glasshouse), as measured by paired Livingstone atmometers, was about three times as rapid as at the other. All the plants at both sites developed the sparse canopy

and total defoliation at flushing characteristic of unthrifty trees in the field. Thrips attack did not occur. The life of individual leaves was short, but much more so in the brightly lit glasshouse with its dry midday atmosphere (R.H. 50%) than in the contrasted shaded and more humid outdoor site. Murray (1953, p. 18) reporting observations made on 480 trees which have so far never suffered a general cacao-thrips attack records " Under heavy shade leaves persist for anything up to a year, whereas in full light the production of each new flush of leaves leads to a heavy fall of old leaves, a phenomenon ameliorated to some extent by manurial practice." The independence of this phenomenon of cacao-thrips attack was noted when a field of unshaded cacao on a heavy soil (Brasso Clay) was successfully sprayed with BHC in the early stages of a cacao-thrips outbreak. Cacao-thrips were virtually eradicated, as determined by inspection. Nevertheless, the flushing habit of the sprayed field showed no difference from that of unsprayed fields adjoining, which also had been attacked by cacao-thrips.

It is evident that the foliar histories and debilitation observed by Reyne can be induced by environmental conditions which commonly prevail in cacao-growing areas. In such circumstances the feeding-punctures inflicted by cacao-thrips would undoubtedly accelerate breakdown of the leaf-cells which were actually attacked, but the very evident fact that leaves attacked, even heavily, by cacao-thrips do not fall until long after the attack has subsided, and, if then, only when a new flush of growth is emerging, indicates that leaf-fall is not a response to the perfusion of the leaf by any systemic toxin spreading from the feeding-punctures.

In Surinam even the most healthy and vigorous trees are attacked.

In Fig. 3 it can be seen that cacao-thrips were present to some extent on the most vigorous trees in the field. It is not to be inferred, however, that the foliar condition of the best trees was optimal at the time when cacao-thrips was present. The important point is not that cacao-thrips survive on these hosts, but that they fail to build up large populations. If Reyne should mean that the most healthy and vigorous trees are *heavily* attacked it is necessary to seek information on his standard for such trees. If his figure (Reyne, 1921, pl. XX) is a typical example, it would appear that the standard is not exacting. The widespread adoption of clone ICS 95 within recent years for planting in Surinam suggests that local conditions are sufficiently adverse to warrant adoption of one of the more hardy types of tree.

Thrips at times has done damage on almost every plantation and in all fields, also in those that were in the best condition of cultivation.

As is evident from Fig. 3, which shows the incidence of cacao-thrips on the best cacao soil type in Trinidad, in a field where cultivation methods, as currently accepted, conform to a high standard, it is clearly not justifiable to assume that these advantages are sufficient to offset adverse effects of seasonal weather in relation to highly local variations in the soil environment. Reyne's observation not only fails to add support to his contention that the cacao-thrips is a primary pest, but suggests that he was unaware of the *dynamic* relationship between tree health and environment, and of the mosaic-like variation in nutrient and physical characteristics of the soil of a cacao field.

A relation between thrips attacks and witchbroom disease was never noticed.

The contention here is that if debilitated trees are more heavily attacked by cacao-thrips, then trees weakened *by disease* should also be more heavily attacked. As Witches' broom disease is, by definition, a disease, then if the theory is correct, heavy attack by cacao-thrips should be found on trees which have been infected with the fungus. As Reyne found no such correlation, he implies that the theory must be discredited. Reyne himself, however, points out that Witches' broom disease is not seriously debilitating, and does not cause death of trees. A point of equal importance is that the presence of the fungus does not induce, in leaves of the affected tree, either on the " broom " itself or on unaffected shoots, any appreciable degree of specific nutrient deficiency. The foliar conditions favourable to multiplication of cacao-thrips are, accordingly, not more developed on infected trees than on uninfected, and in consequence no heavier attack by cacao-thrips is to be expected.

(1) *It is, however, admitted that the risk of thrips attack is increased in weakened trees whose foliage has become scanty and where generally more tender leaves are present than in healthy trees.*

(2) *In all food plants the young leaves are preferred to the old ones.*

(3) *Cacao-thrips cannot feed on . . . very young leaves of cacao, as breeding experiments indicate.*

(4) *A distinct relation between abundance of thrips and abundance of young leaves (their most favoured food) was not noticed.*

The first statement can only mean that on " threadbare " trees more flushing shoots are produced at one time than on a vigorous tree, and (or) that the flushes follow one another more frequently than on a healthy tree.

If this circumstance is accompanied by an admitted " risk of thrips attack," it might seem strange that no obvious relationship was found between cacao-thrips incidence and the presence in abundance of young leaves.

It may certainly be agreed that the risk of cacao-thrips attack is greater in weakened trees, if their condition is the result of malnutrition over a long period. It is also possible to find no relationship between abundance of cacao-thrips and abundance of young leaves, if observations made at different flushing periods, and on vigorous and unthrifty trees, are lumped together as a basis for generalisation.

So much for the reasons advanced by Reyne for rejecting the view that cacao-thrips attack is secondary.

To be fully acceptable, however, an explanation must be consistent with all the known facts : it now remains to account for the good results that have been claimed by various workers from the use of insecticides and repellants.

If cacao-thrips is, at all times, a secondary pest, and can form large colonies only where the leaves of cacao have been " conditioned " by other factors, protection from, or timely removal of, cacao-thrips would be expected to confer no appreciable benefit on healthy vigorous trees, but would relieve constitutionally weakened trees of an additional strain on their photosynthetic mechanism. If, on the other hand, cacao-thrips were a primary pest (like flush-eating beetles), then protection of the foliage from injury would be expected to save those pods *of the same crop season* for the loss of which cacao-thrips would other-

wise have been considered responsible, and that approximately equal benefit would be conferred on every tree.

Urich (1919) suggested sprays containing nicotine and soap, nicotine and starch paste, nicotine and resin wash, and nicotine sulphate and Bordeaux mixture, for use against cacao-thrips. The last-mentioned combination was designed to kill moss and to combat fungi while the nicotine component destroyed cacao-thrips. Reyne found that leaves sprayed with lead arsenate, Bordeaux mixture, or even milk of lime were avoided by cacao-thrips in the field.

Results of spraying have been given by Reyne, De Verteuil and De Verteuil (1930, p. 332) and Pound (1940a, p. 65 ; 1940b, p. 80). All report beneficial effects from the use of Bordeaux mixture. Reyne, however, adds " When trees were . . . in a starving condition with very scanty and sickly foliage spraying was not successful." De Verteuil and De Verteuil like Reyne (1921, p. 210) noted that the foliage of sprayed trees was denser than that of unsprayed. Pound (1940a, p. 66) reported that spraying had little effect on crops in the first year, while in the following year (1940b, p. 80) he added that spraying had not increased crop on two of five sprayed plots and, therefore, could not be considered immediately beneficial, although the sprayed canopy was definitely thicker than on the unsprayed plots.

As noted elsewhere the present writer sprayed a block of cacao about an acre in extent with BHC, and, although reduction of the cacao-thrips population was complete, no differences were observed either in the crop or in enhanced longevity of foliage (the principal cause of a denser canopy) between the sprayed block and adjacent unsprayed blocks on two sides. The tree population in all three blocks comprised only a few of the ICS clones and their numerical representation in each block did not differ greatly.

This result is clearly contrary to what should have occurred if cacao-thrips damage is the *primary* factor responsible for leaf-shed. Reyne (1921, p. 207) claimed that " the injury caused by thrips is increased through dying of the leaf tissue and again by the fact that leaves with dead spots fall. It is owing to the continual falling of leaves that the severe damage is caused which is seen on cacao estates." Accordingly, on this view, survival of protected leaves should have been evident, even though the benefits therefrom did not extend to the successful maturation of a larger number of pods.

It is clear that this and other negative results can be reconciled with the beneficial results noted by Pound, De Verteuil and De Verteuil and Reyne only by assuming that, as all the sprays used were effective in repelling or killing cacao-thrips, the observed differences in response are to be attributed to the direct effect, or lack of effect, of the spray itself on the foliage of the tree.

Referring to the use of Bordeaux mixture (and possibly milk of lime) Reyne (1921, p. 212) admits that " in spraying young cacao plants sometimes striking results were obtained, which may be partly due to growth-promoting properties of the spray." De Verteuil and De Verteuil believed that the beneficial results derived from spraying with Bordeaux mixture were to be credited in part to its effect in directions other than the repelling of cacao-thrips, such as in the destruction of moss on the boughs.

Now Evans (1953, p. 45) has demonstrated a low level, relative to a normal site, of iron, manganese and copper extracted by Morgan's reagent from leaves collected at San Juan Estate on a calcareous soil, and Evans and Fennah (1953, p. 42) recorded positive responses to leaf injection of iron, manganese, copper, magnesium and cobalt on a clay soil, and noted that iron is one of the most frequently unavailable elements. Describing the effects of severe nutrient unbalance involving iron, Evans (1953, p. 43) notes that affected " leaves absciss at an early stage and frequent flushing occurs. The trees show bare branches with several young flushes and a few persisting older leaves. In due course carbohydrate reserves become exhausted and die-back—first of twigs and later of large limbs—occurs. Bearing is severely affected and death of the tree may finally occur." He adds that " this sequence of events also occurs with prolonged nitrogen deficiency, particularly in over-exposed trees." This description agrees with that of the effects of cacao-thrips damage as interpreted by Reyne. Fennah and Evans (1953, p. 49) report that restoration of the normal green colour in chlorotic cacao leaves followed the application of an acidified spray of iron sulphate solution, and it was suggested that two or three such applications per annum would be sufficient to keep the trees reasonably healthy. Spraying experiments with iron sulphate at two other sites in the vicinity gave similar results, while a marked response to a spray of manganese sulphate was noted on Robusta coffee on the clay soil site mentioned above. There is little doubt that copper and zinc can effectively be supplied to cacao leaves by spraying, and it is to be expected that where cacao leaves respond to intervenal injections of copper, the trees will be directly benefited by a spray of Bordeaux mixture. The spraying experiments of De Verteuil and De Verteuil and of Pound at Marper Cacao Experiment Station were carried out on soil types known to be poorly aerated during the wet season and (frequently) with a pH near neutrality. In such conditions the seasonal development of foliar deficiencies in available iron, manganese, copper and zinc is highly probable.

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Summary

After a brief summary of the life history of cacao-thrips (*Selenothrips rubrocinctus* Giard) and a list of host plants, data are given on zonation of the insect on the cacao tree and other hosts, its abundance in relation to time, leaf-flushing, yearly weather, and genetic constitution, yield, and growth habit of the cacao tree, together with its spatial abundance in relation to trees on a single site. Its abundance in relation to light, soil moisture, atmospheric humidity and foliar status of the cacao tree in respect of nitrogen, potash, and minor nutrient elements is reviewed, largely on the basis of data already published.

The annual increase in the cacao-thrips population of cacao fields in Trinidad is considered to be determined primarily by the increasing availability, as the wet season progresses, of foliage in a condition suitable for food. The condition is thought to be associated primarily with retarded protein synthesis and an enfeebled protein-stabilising mechanism. It is postulated (1) that a single

incision of such "conditioned" leaf tissue will yield a greater supply of food in solution than a single incision of leaves in which protein synthesis is not retarded and the protein-stabilising mechanism is functional to its highest degree, and (2) that cacao-thrips multiplication at its highest rate can take place only when feeding is efficient.

All the data are examined in the light of this hypothesis, and the effect of specific relevant factors is evaluated. Observations which have led other workers to reject the view that cacao-thrips attack on cacao is secondary are discussed and it is shown that they are accommodated within the framework of the general scheme.

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Some Aspects of the Plant Improvement Programme

by

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A LARGE-SCALE plant improvement programme for cacao was begun in 1948 under the present Cocoa Research Scheme. Now that intensive observations have been started on the oldest progenies, it has been felt desirable to present a review of the programme and its prospects in the light of information already available.

The need for improvement in cultivated cacaos scarcely needs emphasis. The bulk of the world's cacao is produced from relatively low-yielding trees, the inefficiency of which becomes more marked the more the cost of production rises. Increase in productive capacity and diminution of losses from diseases by the use of resistant material become, therefore, a matter of every pressing urgency.

The cacao population of the New World consists of a highly diversified structure of types, some of which are locally relatively uniform ; other populations are of hybrid origin and represent mixtures in which some recognisable types can be discerned. The Trinidad population is one of these and the existing trees are the descendants of hybrids between the numerous kinds of cacao that have been introduced to the island over some five hundred years of cultivation of the crop. A population of high genetical variation has been produced which, whilst it consists largely of trees of low productivity, offers considerable scope for selection and improvement.

A notable step towards improvement was made by Pound in the early 1930's through the selection of certain high-yielding trees, the vegetatively propagated progenies of which are being used in Trinidad and other parts of the world as replacements for inefficient seedlings and as planting material for new areas. Individual plant selections have also been made in other territories—Grenada, Dominica, Costa Rica and Colombia, to name only a few. The prevalence of Witches' broom disease in Trinidad prompted the introduction of numerous trees in 1937 from Ecuador and Peru, with the hope that in them a degree of resistance would be found higher than that which exists in the local population.

While on a broad basis fundamental research on systems and techniques in cacao breeding can be applied to other areas, the results of the present programme are directly applicable only to Trinidad conditions ; and even then, there is no assurance that material selected at River Estate will be immediately suited to conditions elsewhere in Trinidad. The authors feel it to be a shortcoming of the present programme that the Research Scheme has no land at its disposal, and under its own control, for growing progenies under conditions of soil and climate more generally typical of the island than those of River Estate. A seedling six months old can readily be propagated as two genetically similar individuals ; if one were planted at River Estate and the other on a more representative soil there would be some assurance, from a consideration of performance at both sites, that a selection would be of general utility throughout Trinidad and, with rather less assurance, elsewhere in the West Indies.

Both asexual and sexual methods of propagation in cacao may be used. Asexual propagation is done mainly with cuttings and provides a simple, if costly, method of producing uniform planting material from a heterogeneous population, the seedling offspring of which are quite unpredictable in performance. The use of seed appears justified for the planting of extensive new territories, and in circumstances where the parent material shows no great range of variability or where precise uniformity is not desirable. In variable populations strict control of seed production is necessary and the breeding programme is more involved, since selection must be made for types which will produce progeny of the desired characteristics.

Aims and Objects

The following factors are, at present, considered important from the point of view of cacao improvement. It is hoped, over the next few years, to accumulate information by intensive tree-to-tree studies as aids in the breeding techniques.

Yield. Increase in yield is the most important factor in cacao improvement. It is difficult to estimate the average yield per tree per year in a territory even as small as Trinidad ; but a figure of 1 lb. of dry, fermented cacao per tree would probably not be too inaccurate. A wide variation in yielding ability exists amongst the Trinidad population and considerable increases, of the order of four and five times, have been achieved and are to be expected by the cultivation of selected high-yielding trees as vegetatively propagated clones.

The intra-clone variation has been observed to be fairly large. Some of Pound's selections are remarkably precocious—this, too, has been noted in selections made in other territories ; earliness of bearing is obviously of great economic importance where rehabilitation of cocoa-producing areas is being practised with the aid of clonal cuttings. It is, perhaps, disappointing that only a small proportion of Pound's selections shows this desirable precocity, and its low incidence is, perhaps, to be explained simply by the fact that selection for heavy bearing amongst mature mother trees of unknown age does not automatically select for early bearing. It seems reasonable to suppose

that clones established from seedlings which show good bearing capacity from their third or fourth year of growth will reproduce the early-bearing habit ; the authors confidently expect, therefore, that selection of heavy-bearing material from amongst the many thousands of young seedlings raised since 1948 will result in a proportion of precocious bearers higher than that which emerged from Pound's selections. This point is to be tested experimentally by comparing the performance of cuttings taken directly from early- and late-bearing seedlings. It might be objected that early bearing would result in short productive life ; in the absence of data to confirm or refute this suggestion little more can be said, except to point out that even if cuttings of a precocious clone had a productive life span of only 20 years, a 5% per annum replanting of any given area would give yields still a long way in advance of any seedling material now available, and would automatically ensure that " the capital value of the estate is maintained and even continually enhanced, instead of being allowed to deteriorate by the gradual passing of the fields into an uneconomic old age " (Cheesman, 1946).

Observations on clonal performance indicate clearly that certain clones give their best yields under certain environmental conditions ; other clones are less dependent upon these conditions. In the absence of any measurable character which would allow the prediction of a clone's performance under any set of specified conditions, it will always be necessary to conduct clonal trials with new selections, and such trials should be conducted on a regional basis as wide as possible.

The most practicable method of assessing yield of individual trees, when several thousands have to be observed, still remains to be found. It is a fortunate circumstance that selection for early and heavy bearing amongst our maturing seedlings will allow the by-passing of those seedlings which show no early promise, but the problem still remains of obtaining an accurate yield estimate from those that are under intensive observation. Total healthy pod production per tree is a statistic that can easily and reliably be obtained, but the assessment of the average pod content per tree and the average conversion figure for wet weight of beans into dry fermented cocoa present more difficulty. The variation in individual pod content is controlled by several factors and a study of these will have to be undertaken to gain an understanding of yield variability. Pod size is not of itself an important character in cacao production except in so far as bean size and pod size are correlated. Perhaps it would be unwise to stress too heavily the need for a strictly accurate yield assessment of any potential selection, since it is likely that when such a selection is clonally propagated the yield variation from environment to environment will be much greater than the small errors made in estimating the parent tree's production.

Pollen compatibility. It will be desirable to know the compatibility status of any selection made in the next few years, although it will be remarkable if any selection made for vegetative multiplication is rejected on account of self-incompatibility. The long-term clonal trials which have been conducted with ICS material in Trinidad and GS material in Grenada have demonstrated very clearly that self-incompatibility is no handicap to pod production under the conditions in which the experiments have been conducted ; indeed, the majority of the heaviest yielding ICS clones are self-incompatible. What remains to be discovered is the minimum proportion of self-compatible trees required in a mixed planting of self-compatibles and self-incompatibles before cross-pollination on the latter becomes a limiting factor. An experiment is to be planted this year at River Estate to find out over what distances pollen is transferred from one tree to another ; the results of this trial will allow prediction of the proportions of compatibles and incompatibles required in a mixed planting of clones.

Research in Trinidad on incompatibility has demonstrated that a tree's compatibility status can quickly and definitely be determined by the examination of the ovary of only a single flower which has been guarded and adequately pollinated. A self-compatible tree will show 100% fusion of male and female gametes, and fusion of the second male gamete with the polar nuclei, in every ovule which has been fertilised. A self-incompatible tree, on the other hand, may show varying proportions of non-fusions ; the ratios of non-fusion to fusion recognisable to date in incompatible matings are 1 : 3, 1 : 1, 3 : 1 and (possibly) 15 : 1. If, therefore, a microscopic examination of the sectioned ovary from a selfed flower, taken at 72 hours after pollination, reveals a proportion of ovules wherein nuclear fusion has not taken place, then the tree from which the flower was taken can be classified as self-incompatible ; where no fusion failures are noted, the tree will be self-compatible. Though technically less easy than making observations on the development or fall of a large number of hand-pollinated flowers, this new test of compatibility is far less time-consuming and gives an immediate, decisive answer. A considerable number of progenies arising from controlled pollination have already been examined and it is hoped eventually to be able to put forward a genetic scheme which will accommodate all the discovered facts.

The incidence of incompatibility in *Theobroma cacao* does, however, lead to a limitation of the possibility of making certain crosses. It seems, at the moment, that a self-incompatible tree will set fruit if pollinated with pollen from another tree which is itself self-compatible, or if receiving pollen from another tree which has no gene of an allelomorphic series (of which seven are certainly known in the local Trinidad population and introductions that have been examined) in common. Where two incompatibles cross successfully (e.g., SCA 6×ICS 60), the resulting progeny will all be incompatible, but because both parents carry different incompatibility alleles, the offspring will show some cross-compatibility amongst themselves, and a proportion of them will be able to backcross with one or other of the parents. The ability of the plant breeder to backcross an interesting seedling with either parent will, therefore, be a matter of chance, depending upon which incompatible parent donated the incompatibility allele to the particular seedling. An extreme case would be expected to arise occasionally where the progeny of a cross between two self-incompatibles would be completely cross-incompatible and completely incompatible with either parent ; further improvement on any selected member of the progeny could then be made only by introducing an entirely new parent into the programme.

More directly, of course, incompatibility puts a barrier between two self-incompatibles carrying similar members of the allelic series. ICS 43, for instance, cannot be crossed to ICS 89—indeed, it would appear that no self-incompatible trees of Trinidad origin are cross-compatible.

Again, inbreeding with the object of establishing pure lines, can as far as we know, only be achieved with self-compatible material. Finally, if uniform seedling material can eventually be realised from crosses made between inbreds, then it will be essential to know how much incompatibility will be manifested by the progeny—we already know that a cross between two self-compatible parents (e.g., ICS 1 and ICS 45) can give progeny all of which are self-incompatible.

Disease resistance. The fungus, *Marasmium perniciosus* Stahel, which causes Witches' broom disease on cacao, is distributed throughout most of the areas in South America where the crop is cultivated. The disease was first recognised in Trinidad in 1924 and eventually accounted for very severe crop losses—and at a time when cocoa prices were extremely low. Although the whole Trinidad population appears to be susceptible to the disease, it was observed that considerable variation in susceptibility occurs. The best control of the disease would be achieved by growing the most resistant trees, providing they combined resistance with other desirable features. After a lengthy visit to various parts of the Amazon basin, Pound, in 1937, introduced to Trinidad a number of progenies of trees he found uninfected at the time of his encounter with them. Careful observations on these introductions, made by the Trinidad and Tobago Department of Agriculture, have shown that they possess varying degrees of resistance to the disease. Strong resistance has been noted in some trees, especially amongst the SCA (Scavina) progenies, indicating the heritable nature of resistance. It is unfortunate that though these trees combine resistance with good yield potentialities, they lack certain characteristics which make them generally unacceptable to commerce. The main effort in the breeding programme has been to combine resistance characteristics of these introductions with the commercially acceptable Trinidad selections. It will necessarily require considerable time before any of the seedling progenies can definitely be classified as resistant because of the difficulty of ensuring uniform exposure to infection in the experimental plantings. Studies in the correlation of reactions of infected young seedlings (Holliday, this report) with those of mature trees are being carried out. If good correlation is observed, then the technique of infecting germinating seeds would enable a rapid sorting of material into susceptible and resistant types.

As with Witches' broom disease, the Trinidad population also shows varying degrees of susceptibility to *Phytophthora* attack. No local trees are known which show any considerable resistance to the disease, so that until material becomes available which is proved resistant to pod rot, there seems little prospect of breeding for resistance to this disease. One introduction from Brazil, alleged to be resistant, has been made, but the young plants have not yet flowered. Several abortive attempts have been made to obtain material of the famous clone Lafi No. 7 (Eden, 1953) and it is a matter of conjecture how long it will be before any is established in Trinidad.

Bean size. The size of fermented and dried beans is of some commercial importance because of the wastage of the testa which, as a general rule, increases in inverse proportion to the size of the bean. Large beans are preferred in industry. It has been suggested (Knapp, private communication) that the selection lower limit should be between 1.2 grams and 1.0 gram per dry bean, depending to some extent on the absence of presence of compensating desirable characters respectively. In terms of bean wet weight, the figures become 3.0 and 2.5 grams ; such lower limits will usually be easily passed in progenies arising from crosses made between parents which themselves possess large beans, but may prove difficult in the crosses made for Witches' broom resistance where the Amazonian parents are characterised by smallness of bean. The average bean weight in selections is a readily determined statistic and merely requires that when pod contents are weighed the bean numbers are also recorded ; and this can be further checked when bean samples are fermented and dried.

Shell content. The valueless testa should, of course, represent as small a fraction of the bean weight as possible, consistent with the shell being sufficiently tough to be resistant to mechanical and insect damage. It has been suggested that a maximum limit of 14% in dried, fermented beans should be the selection standard. The average shell content, again, is a readily determinable quantity from even quite small samples of fermented beans.

Fat content. The manufacture of eating chocolate requires a proportion of butter fat in excess of the normal content of the bean, the extra amount being provided from the processes leading to the manufacture of cocoa powder. Chocolate factories often have to buy extra cocoa butter. It will be necessary, therefore, to see that the proportion of fat in the beans of any potential selection does not fall below a figure of about 53% ; a higher proportion, coupled with other desirable characteristics, would definitely be of value. The estimation of fat content in bean samples is not unduly difficult but may prove rather time consuming. It is not anticipated that the chemical constitution of the fat in progenies arising from crosses between cacao types will change in any marked manner, but it may be necessary to check that the melting point of the extracted fat does not fall below 31°C.

Flavour. A variety of flavour types is recognised by the industry. For some of these there is a special but small demand. No information is yet available on the causes of flavour differences or how they are genetically controlled. When Pound made his selections twenty years ago it was thought that selection for large, plump beans would simultaneously select from the population those members with the best flavour characteristics, but tests made in later years on bean samples from the clones have indicated that the correlation between bean size and flavour, if it exists, is a most uncertain one in the Trinidad population. Perhaps the correlation might have some validity when beans from all over the world were compared—Venezuelan criollo *en masse* would undoubtedly rate as a better flavoured cocoa than West African *en masse*, but when it comes to individual trees there can be no assurance that a single tree of the Venezuelan criollo type would give better flavoured beans than a single randomly chosen tree of the West African forastero type. The senior author still remembers the verdict given on a sample of fermented beans from the Grenada selection, GS 32 ; the fresh beans from this selection are flat, lozenge-shaped and very dark purple in colour, yet the fermented beans were described as developing an extremely fine chocolate flavour. It would seem that the plant breeder has absolutely nothing to guide him, from any external or internal characters of a tree, in predicting what flavour any individual selection will develop from its processed beans. Because his selected tree has large,

rough shelled pods containing large, rounded and pale-tinted beans this is no guarantee that the flavour developed on roasting will be acceptable. The only test available to him is a real flavour test ; he has to ferment as optimally as possible as large a sample of beans as he can obtain, roast the beans and prepare a specimen for tasting. In any one of these operations the final assessment can be biased by faulty procedure. He may over- or under-ferment his sample, the fermenting beans may acquire off-flavours from extraneous sources, his roasting may not develop fully the latent flavour and, finally, having obtained his tasting specimen he will receive conflicting reports from the tasting experts.

Too great an emphasis on the flavour developed from single trees or clones is perhaps unwarranted. For reasons quite unconnected with flavour, no plant breeder would recommend the use of only a mere handful of clones in any planting or replanting programme : he would always advise the use of a wide range of clones, provided always that the range did not include too extreme types (uniformity of bean size and fermentation time would need regulation). It is felt, from both theoretical and practical considerations, that the flavour resulting from a generous mixture of clones would tend to normality. A single clone could hardly be expected to reproduce the flavour characteristic of any geographical area, simply because such traditional flavours have become established by the mingling of the produce of thousands of different genotypes. The so-called Trinidad flavour, for example, is some undefinable blending of flavours from innumerable individual local trees, any one of which alone would not be recognisable as giving Trinidad flavour. But given several hundred such individuals, their mixed fermented beans might well reproduce the required flavour. Where, by fortunate coincidence, a single Trinidad selection was found to give the traditional flavour directly, then so much the better ; but the plant breeder in the West Indies might well be adopting a wrong policy if he decides to reject every selection (promising in other respects) that by itself does not give the local tradition of flavour.

It will certainly be necessary, none the less, to submit beans from possible selections to individual flavour tests, not so much with a view to trying to discover the few which reproduce the Trinidad flavour as individuals, but more with the object of eliminating those which have so strongly marked undesirable flavour characters—such as extreme astringency—that the presence of their beans in a mixture would possibly be deleterious. Having rejected any selection for such adverse characters, it would then be necessary to try various mixtures of the produce of the remaining selections to verify that the flavour of the mixture did not depart seriously from the Trinidad standard. It is fortunate that there is a small tasting panel in being at the College, capable of giving an opinion on about 300 samples a year. It is not possible, at the present time, to estimate in advance how many seedlings will be chosen as promising material for more intensive study ; but if large numbers are entertained, then it may be necessary to have extra staff to deal with all the samples that come to hand. It seems likely that the panel will be called upon to give its judgment on the closeness or otherwise of prepared samples from other Caribbean areas against a standard for each area ; in these circumstances it seems almost certain that the mechanism will need enlargement.

Summary

It is obvious that the selectionists will be fully occupied with assessments of the potential value of individual selections over the next few years. To conclude this paper, it may be felt desirable to recapitulate the lines of approach that will be followed.

Because yield is of major importance, the first step will be to obtain reasonably accurate records of the yields of promising individual trees ; and because earliness of bearing is also desirable, attention will automatically be focused on those seedlings which fruit in their early life. It will be necessary to check the hypothesis that earliness of bearing is a character which can be handed on to vegetatively propagated material. To avoid the pitfall of selecting material which is promising only because it is favourably situated, it will be desirable to have some record of the yields of the immediate neighbours of any possible selection, to ensure by comparison that the tree under observation is genuinely superior to those near to it.

Simultaneously with the collection of yield data, it will be necessary to judge, as far as possible, the resistance status to Witches' broom and pod rot diseases of each potential selection. Any heavy bearer which shows abnormal susceptibility to either disease would be discarded.

Information on average bean size will be collected along with gross yield records. Any selection with an average wet bean weight under 3 grams would be suspect.

As early as possible it will be desirable to ferment on a small scale a sample of the beans from any potential selection. From a sub-sample of the dried beans it should be possible to derive estimates of the dry bean weight, its shell content and its fat content. The other portion of the prepared beans will be submitted to a flavour test, by the small panel, after being made into chocolate. Any selection noted as having any marked off-flavour would probably be rejected out of hand unless it had some more than compensating feature in other directions. If some dozen or so selections pass all the criteria simultaneously, they could then be checked as a group to see that the composite flavour was not abnormal in any way.

Once accepted as worthy of consideration, all clones should be given extensive regional trial in as many areas as possible, where land is available, before final acceptance.

Some slight adjustment of selection criteria may have to be made in some cases. If abundant material comes to hand, the criteria could be rigidly observed, but if the total number of selections is disappointingly small it may prove necessary to impose less exacting criteria, or to balance some small shortcoming against an overwhelmingly desirable trait in some other direction. Not all selections need necessarily reach the stage of large scale distribution as cuttings ; some material may be selected for further improvement or as being highly suitable as a parent to impart one or more characters in further breeding work.

Plant improvement is progressive work and usually repetitious. The best and most promising material which emerges from the first serious attempts at improvement will be the starting point for the second cycle of breeding. Somewhere along the road it may be necessary to introduce material from other parts of the world into the breeding programme and it is for this reason that specimens from other geographic areas are being collected when opportunity presents itself. When further knowledge is gained

of the inheritance of characters of major importance, and with improvements in selection techniques, material from both sources, local and introduced, will form the basis for better and more efficient breeding programmes.

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A Shade and Fertiliser Experiment with Cacao. IV

by

D. B. Murray

THE previous history of this experiment has been reported by Evans and Murray (1953), Murray (1953) and Murray (1954). In 1953, a new treatment was introduced to determine the effect of shade removal on plants previously growing at different light intensities. This comparison is of considerable practical importance for the cutting out of temporary shade from young cacao in the field and its subsequent growth under no shade or light permanent shade is often a critical stage in its development. Provision had been made in the layout for such a treatment and, accordingly, in June, 1953, the artificial shade of bamboo slats was removed from half plots of each shade treatment.

General Management and Observations

During the crop year 1st September, 1953, to 31st August, 1954, fertilisers where specified, were applied at the following rates in lb./tree :

	12/10/53	4/2/54	*Total*
Ammonium sulphate (N)	½	1	1½
Superphosphate (P) ...	¼	½	¾
Sulphate of potash (K) ...	¼	½	¾

The removal of the shade led to considerable loss of leaf from plants previously shaded to 15% and 25% of full light and the new flushes produced smaller and paler leaves, the type of leaf already associated with development at high light intensity. Less effect was shown on the plants previously shaded to 50% and 75% of full light. Weed growth which had been very sparse under the heavy shade increased considerably.

Some six months after the removal of shade, however, the plants had in general developed closed canopies as a result of the rapid growth of lateral branches and increased leaf production. The previous lax habit of the heavily shaded trees did not make for a well shaped tree and a certain amount of pruning of low branches was necessary in October, 1953, four months after shade removal.

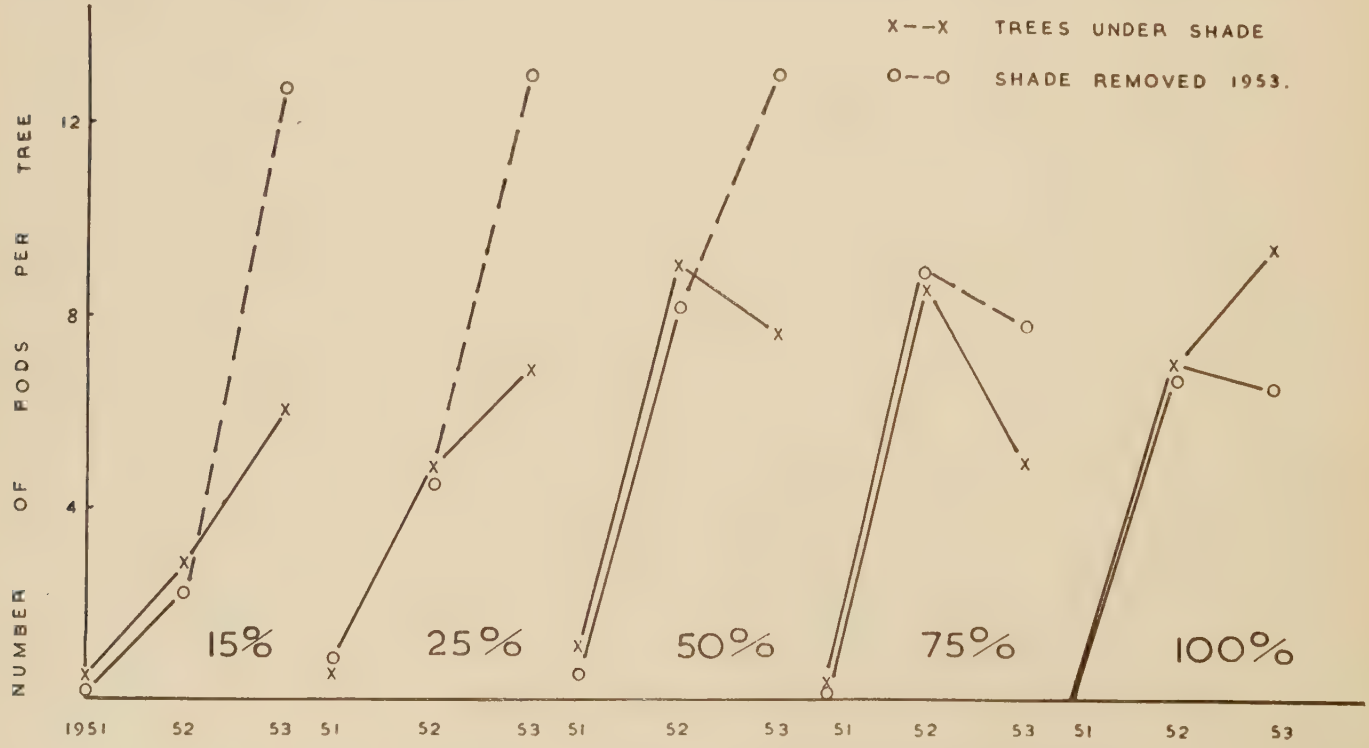

FIGURE 1

Comparison of the effect on yield of removal of shade with retention of shade.

FIGURE 2

Monthly distribution of crop from trees under shade and trees from which shade has been removed.

Yields

The trees were harvested monthly and the numbers of pods per tree are given in Appendix I. In the analysis of variance the distinction is made between trees now growing unshaded, but previously shaded and trees never grown under shade.

The overall effect of shade removal is shown in Fig. 1. The full lines give the yields of trees growing at the specified light intensities, the broken lines after 1952 the effect on the 1953-54 crop of shade removal.

For plants previously growing at only 15% and 25% of full light, removal of shade practically doubles the crop over trees continuing at those light intensities. At 50% light the effect is less marked, but still significant statistically, at 75% the difference is not significant and at 100% since no previous shade had existed the duplicates give a measure of the variability, which is far higher in the 1953 crop than in the 1952.

The increase in yield over the 1952-53 crop of the plants continuing growth at the low light intensities must be associated to some extent with the development of shoots through the bamboo slats. This has increased the nominal light intensity at which the trees are supposed to be growing. The general conclusion is still valid, however, that too heavy shade on young cacao limits early yields.

It is of interest to examine the spread of the crop and this is shown in Fig. 2. The increased crop that results from shade removal does not appear as a constant monthly increment but occurs almost entirely in the period of the June crop. Thus shade removal leads to a similar pattern of cropping to that shown by the plants that had always grown without shade. This pattern of cropping in young plants is discussed elsewhere (Murray, 1955).

Nutrient Interactions

In the 1952-53 crop (Murray, 1954), significant responses were secured to both nitrogen and potash manuring, but not to phosphate, and these responses were shown to interact with light intensity, the greater the light intensity the greater the responses, primarily to nitrogen, and to a smaller extent to potash.

The results for the 1953-54 crop, Table I, both confirm and extend these results.

TABLE I

Mean number of pods per tree in relation to shade removal and fertiliser treatment.

(*a*) Nitrogen effect

	No Nitrogen	Nitrogen	Increase
Shade	7.13	6.88	—0.25
Shade removed ...	8.96	12.18	3.22
Increase	1.83	5.30	—

(*b*) Potash effect

	No Potash	Potash	Increase
Shade	4.91	9.11	4.20
Shade removed ...	8.98	12.15	4.17
Increase	4.07	3.04	—

(*c*) Phosphate effect

	No Phosphate	Phosphate	Increase
Shade	6.41	7.61	1.20
Shade removed ...	9.48	11.65	2.17
Increase	3.07	4.04	—

L.S.D. 5% manurial means with same shade treatment ±0.74.
L.S.D. 5% shade means with same manurial treatment ±2.31.

As regards the nitrogen effect, where the shade has been removed a significant response to the application of nitrogen has resulted. Where the plants have remained under shade, however, additional nitrogen has had no effect on yield.

Potash as compared with no potash shows a highly significant increase in yield of similar magnitude both with shade and after its removal. With phosphate the increases

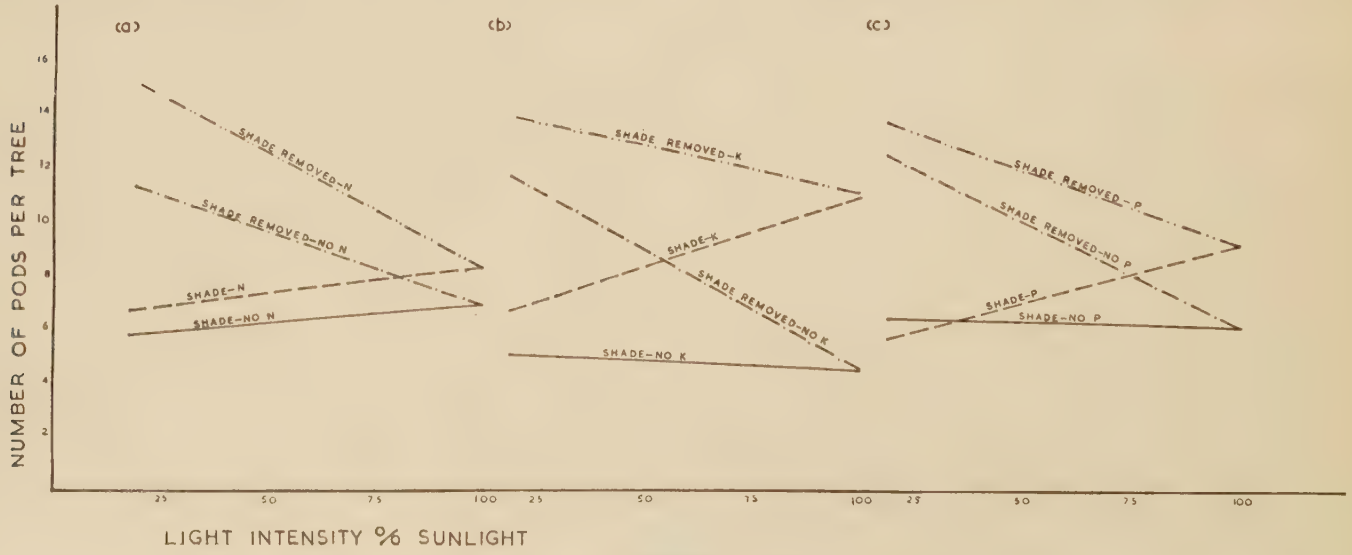

FIGURE 3

Interaction of light intensity and shade removal with (*a*) nitrogen fertilising, (*b*) potash fertilising and (*c*) phosphate fertilising.

are smaller, but it is greater in plants from which the shade has been removed than in plants remaining under shade.

It is necessary next to examine in more detail the interactions of the fertilisers at each light intensity and in Fig. 3 straight lines of best fit have been drawn to show the general trends with change in light intensity.

In each figure the lower pair of lines represent the effect of presence or absence of the fertiliser with shade varying from 15% light to full light. The upper pair of lines show the responses after removal of shade. The two series must meet at 100% light for these plots never having had shade represent duplicates.

Dealing first with the nitrogen effect, the bottom line, shade—no nitrogen, rises with increasing light intensity indicating that heavy shade is limiting yield and also that high light intensity is no longer depressing yield in the absence of added nitrogen.

The shade—nitrogen line runs nearly parallel and not significantly above shade—no nitrogen again indicating that shade is limiting yield and that under heavy shade additional nitrogen does not increase yield. For the plants that have always grown at 100% light there is now no significant increment with nitrogen, as compared with the previous year's crop when the greatest yield increment with nitrogen occurred in full light.

The removal of shade has led to a great increase in yield at the low light intensities. The increment, moreover, is greater with additional nitrogen than without.

Examining next the potash effect, Fig. 3(*b*), shade—no potash gives similar yields at all light intensities. Shade—potash produces an increasing increment of crop as light intensity increases, the maximum effect occurring in full light.

Removal of shade increases the yield of the previously heavily shaded plants, but the potash increment is less than it is for the plants never previously grown under shade. Again the previous history of the heavily shaded plants shows that they had accumulated higher levels of potash in the leaves and it is reasonable to suppose that greater metabolic use was made of this when shade was removed.

The phosphate picture is similar to that for potash, but with smaller effects.

Discussion

The increase in yield resulting from shade removal was not unexpected since it had been shown in the previous crop season that light was limiting yield. The magnitude of the increase is, however, somewhat surprising and may be contrasted with the field experience of planters in Trinidad who lose the Immortelle shade over mature cacao. Loss of leaf occurs, production of new leaves is poor and yields suffer. Usually, however, in such cases the cacao has been growing at a low level of nutrition and lacks the mineral reserves to develop a thick canopy. Where young vigorous trees are concerned shade removal even as drastic as from 15% and 25% light intensity to full light has not had any ill-effect, but rather has led to a substantially greater crop in the following season.

Cacao is generally considered to be a crop very sensitive to its environment and not tolerant of abrupt changes. This would appear to be the case when it is growing under poor conditions, but where young well nourished plants are concerned they exhibit a high degree of plasticity.

The changing role of inorganic nutrition is of considerable importance. During their early growth the main response of the plants, particularly at higher light intensities, was to additional nitrogen. During their fourth year in the field, however, this response to nitrogen has disappeared except where the shade was removed and instead significant effects have been shown by additional potash and phosphate.

It is evident that this is brought about by the changed shade relations of the trees. Considering more particularly the trees growing at the higher light intensities, in their early years and without additional nitrogen they were stunted and slow growing as compared with similar trees receiving nitrogen. Now, however, they have grown sufficiently for self-shading to be appreciable and it has been shown that with heavy shade the plant does not respond to additional nitrogen. With the continuous canopy that now exists right through all treatments light measurements at ground level have shown that less than 0.5% of the incident light is reaching the ground. This is less than in the average estate field under Immortelle shade where sufficient light gets through the combined shade tree and cacao canopies to allow of the development of a weed flora. Practically no weeds are growing in the present experiment.

This means that a very sharp light gradient exists through the canopy. Leaves at the top of the tree are receiving full light, but those at the bottom are heavily shaded. With increasing physical size the trees have become buffered against light intensities, which, on plants of a smaller leaf area, would be too great for optimum metabolism.

Besides the absence of weed competition the low light intensity at ground level results in lower soil temperatures and a reduced rate of breakdown of organic leaf litter. Soil samples taken by the Senior Soil Chemist have been analysed for organic matter and nitrogen, but proved too variable to demonstrate any change in these values or in the C/N ratio as compared with samples taken at the start of the experiment. The significance of these factors in the establishment of what appears to be a closed nitrogen cycle cannot, therefore, be estimated.

On a soil such as this, rather low in available potash and phosphate, it is only to be expected that with the nitrogen requirement of the plant satisfied that these other nutrients have now become limiting and responses to their application have occurred.

The practical results of this experiment have reaffirmed the importance of shade in the early growth of cacao, but the more important result is the demonstration of the strong interaction that exists between this factor and the mineral nutrition of the plant.

Although it has been shown possible to establish cacao with no shade whatsoever and to promote reasonable growth and early cropping by the use of fertilisers better results are obtainable under shade which, however, should be gradually reduced. In practice this is not easy for whereas the cacao should receive more light with increasing size the shade is acting in the reverse direction and reducing the light as it grows. Hence the need for different types of shade which can be progressively removed.

It is clearly not possible to lay down rigid rules for shade and fertilisers under all conditions. On the present site, young under-shaded plants gave the biggest response to nitrogen manuring, but with increasing size the nitrogen response has diminished and substantial responses to additional potash and phosphate have occurred. Factors such as spacing will affect the picture in that at a close

spacing a complete canopy will be established sooner than at a wide spacing. On soils with impeded drainage, water logging of the cacao root system may result in little uptake of applied fertilisers, and the significance of a planted shade in relation to dry season conditions needs elucidation.

These factors will bear on whether the cacao can eventually be grown without permanent overhead shade. The existence of the light intensity—mineral nutrition interaction does, however, explain the past experience of various countries in their use or otherwise of permanent shade and the higher yields associated with no shade. The best criterion of the health of the cacao is the state of the canopy. A thick canopy even without shade indicates a healthy tree. Loss of leaf is associated with nutrient starvation and may be corrected by shade or fertilisers provided these can be absorbed by the tree.

Summary

(1) The effect on yield of removing the shade from cacao previously grown at light intensities of 15%, 25%, 50%, 75% and 100% of full light is described. Shade removal led to an increase in crop in the following year when the plants had previously been growing at low light intensities.

(2) The increase in crop was not evenly spread through the cropping season, but appeared in the period of the late crop, May-June.

(3) The amount of increase in crop was related to the mineral nutrition of the plant. Plants previously heavily shaded showed a response to nitrogen on removal of shade. Plants previously growing at high light intensities, however, showed little response to nitrogen, but a marked response primarily to potash, secondarily to phosphate. The significance of this is associated with increased growth and self-shading of the plant.

(4) The theoretical requirements for the early years of growth of young cacao are discussed. The most important single factor is shade which should be heavy at first and gradually reduced. Nitrogen manuring reduces the ill-effects of too little shade, but once a complete canopy is established no further response is secured to its application. Other nutrients then become limiting, on the soil in question, potash and phosphate.

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Appendix I

Yields in number of pods per tree, 1953-54, means for two trees

S = shaded plants, NS = shaded up to 1953, thereafter unshaded

Light Int'sity	Con		N		P		K		NP		NK		PK		NPK		Totals	
15%	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
1	4.0	10.5	4.5	11.0	5.0	9.0	2.5	18.0	2.0	20.0	16.5	25.5	9.0	16.0	5.0	18.5	48.5	128.5
60	5.0	7.5	6.0	4.0	10.0	9.5	7.5	5.0	2.5	16.5	16.0	12.5	9.5	9.5	9.5	23.0	66.0	87.5
95	0.5	10.5	6.5	13.0	3.5	5.0	8.0	7.0	1.5	9.0	5.5	13.0	3.5	9.0	3.5	23.0	32.5	89.5
	9.5	28.5	17.0	28.0	18.5	23.5	18.0	30.0	6.0	45.5	38.0	51.0	22.0	34.5	18.0	64.5	147.0	305.5
25%																		
1	7.0	5.0	8.5	6.5	4.5	20.0	8.5	19.0	12.0	10.5	6.0	18.0	7.5	30.0	10.0	16.5	64.0	125.5
60	6.0	7.5	6.0	19.0	4.0	8.5	4.0	7.5	8.5	9.0	13.0	12.0	11.5	15.0	15.0	11.5	68.0	90.0
95	4.5	9.0	2.5	19.0	3.0	11.0	6.5	11.0	2.5	13.0	3.5	15.0	9.5	9.5	2.5	10.0	34.5	97.5
	17.5	21.5	17.0	44.5	11.5	39.5	19.0	37.5	23.0	32.5	22.5	45.0	28.5	54.5	27.5	38.0	166.5	313.0
50%																		
1	5.0	29.5	1.5	16.0	3.5	6.5	16.0	6.5	14.0	12.5	5.5	10.5	11.5	6.5	15.5	18.5	72.5	106.5
60	5.5	2.5	10.0	6.5	6.5	4.5	6.0	13.0	5.5	10.5	9.0	7.5	7.5	20.5	3.0	12.5	53.0	77.5
95	6.0	16.5	5.0	16.5	9.5	11.0	8.5	9.0	4.5	22.0	4.5	14.5	10.5	14.0	10.0	27.5	58.5	131.0
	16.5	48.5	16.5	39.0	19.5	22.0	30.5	28.5	24.0	45.0	19.0	32.5	29.5	41.0	28.5	58.5	184.0	315.0
75%																		
1	0.0	2.5	4.5	6.5	2.5	5.5	1.5	6.0	1.0	1.5	6.0	4.0	9.0	2.5	6.0	8.5	30.5	37.0
60	1.0	3.0	3.5	14.0	2.0	8.5	9.0	5.0	9.0	4.0	6.5	6.5	12.0	20.5	7.0	18.0	50.0	79.5
95	7.0	2.5	1.5	5.0	2.0	11.5	7.5	9.0	7.0	9.5	6.5	7.0	5.5	9.0	1.0	9.5	38.0	63.0
	8.0	8.0	9.5	25.5	6.5	25.5	18.0	20.0	17.0	15.0	19.0	17.5	26.5	32.0	14.0	36.0	118.5	179.5
100%																		
1	3.5	0.0	3.5	13.0	1.0	2.0	18.5	0.0	5.5	2.5	7.5	14.5	15.5	9.5	12.0	15.5	67.0	57.0
60	3.0	1.5	3.5	4.5	5.5	2.5	8.0	0.5	5.0	2.5	10.0	15.0	17.5	7.0	13.5	14.0	66.0	47.5
95	4.5	0.5	12.5	1.5	4.0	11.5	5.0	0.5	5.5	5.0	9.5	12.0	42.5	7.0	8.5	12.5	92.0	50.5
	11.0	2.0	19.5	19.0	10.5	16.0	31.5	1.0	16.0	10.0	27.0	41.5	75.5	23.5	34.0	42.0	225.0	155.0

A Stock-Scion Experiment with Cacao. II

by

D. B. Murray and F. W. Cope

A PRELIMINARY account of this experiment has been given by Cope and Murray (1953). The interactions are being investigated of four clones, ICS 1, 45, 60 and 95, used as stock and scion in all combinations.

The experiment was planted in September, 1951, under shade provided by bananas and *Cassia reticulata*. All bananas were cut out in 1953 and the *Cassia* is being progressively removed as self-shading of the cacao increases. Routine applications of fertilisers have been given, 1 lb. per tree in 1953 and 1½ lb. in 1954, of a mixture of 2 parts ammonium sulphate, 1 part superphosphate and 1 part potassium chloride.

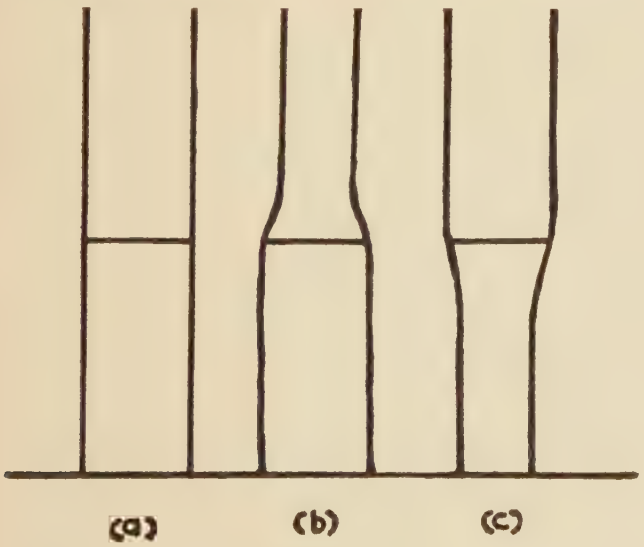

FIGURE 1

Types of graft union (*a*) normal, (*b*) taper, (*c*) overgrowth.

The girth measurements taken above and below the graft union were repeated in 1953 and 1954. Some of the trees produced their first crop in the 1953-54 season.

Experimental Results

Girth Measurements. Measurements of girth were made with a tape both above and below the graft union to give not only the absolute values of these girths but also the degree of disparity in the union which may involve taper, Fig. 1 (*b*) or overgrowth, 1 (*c*) as compared with normal growth, 1 (*a*).

Dealing first with stock girths, Table I gives the mean stock girth at September, 1954, and these are compared with the previous two years' records in Fig. 2.

TABLE I

Mean stock girths in cm., corrected for block differences.

	Scions				
	ICS 1	ICS 45	ICS 60	ICS 95	Means
Stocks					
ICS 1 ...	22.3	19.4	25.7	24.2	22.9
ICS 45 ...	18.9	15.4	22.9	20.9	19.5
ICS 60 ...	21.3	22.0	24.6	22.6	22.6
ICS 95 ...	20.6	16.8	24.6	20.6	20.7
Means ...	20.8	18.4	24.5	22.1	21.4

L.S.D. 5% marginal means ±1.34.
L.S.D. 5% same row or column ±3.15.
L.S.D. 5% not in same row or column ±3.00.

As a stock, ICS 45 has given a smaller girth than either 1 or 60 (sig. 0.1% level) but not 95, the order of magnitude being ICS 1, 60, 95, 45.

The scion that has promoted the best stock girth on all stocks is ICS 60 followed by ICS 95, 1, 45. And from Fig. 2 it can be seen that the position in regard to the scions has remained reasonably uniform over the three year period. On stocks of ICS 60, it will be noted, the scions produce a smaller range of differences than they do on the other three stocks.

In Table II the differences in girth between stock and scion are given, with positive values indicating tapered growth as in Fig. 1 (*b*) and negative values overgrowth as in Fig. 1 (*c*). The change in this relation with time constitutes Fig. 3. From this figure it is clear that the least disparity of union occurs with the self combinations 1/1, 45/45, etc., a result which is to be expected. Any early differences are remaining constant or changing only slightly.

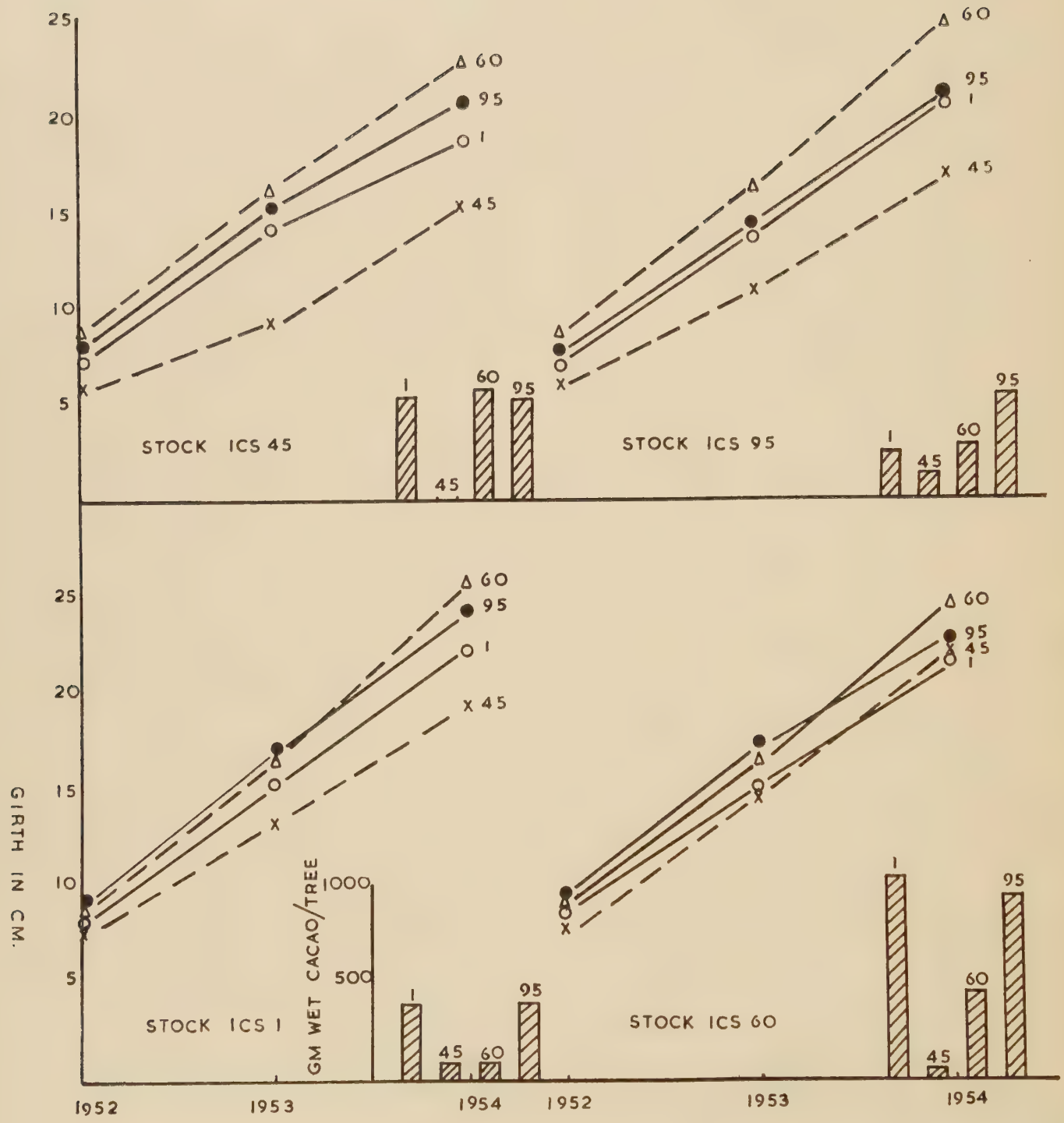

FIGURE 2

Mean stock girth resulting from 4 scions on each stock over three successive years. The yields for 1954 are also shown as grams of wet cacao.

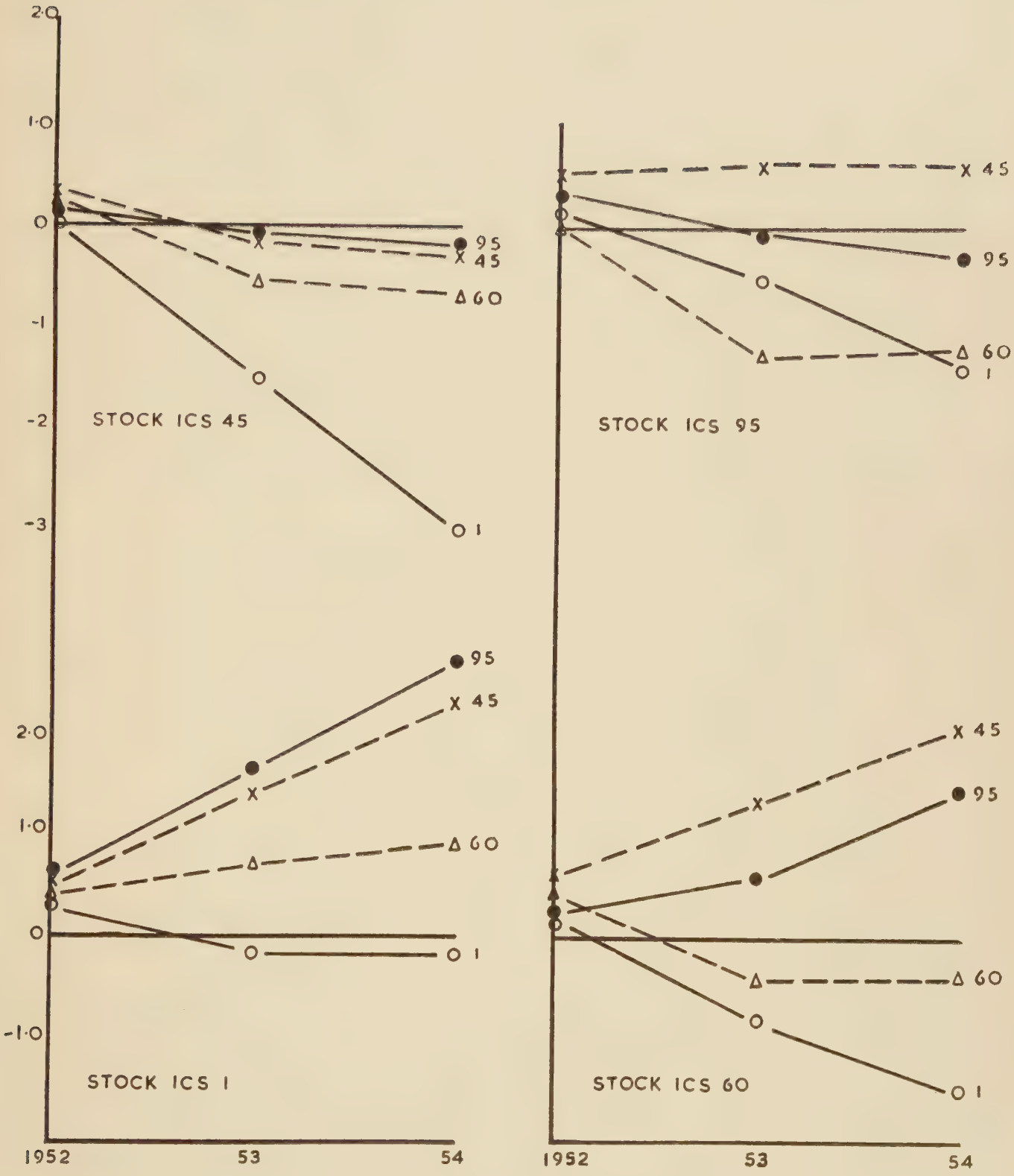

FIGURE 3
Differences in stock girth minus scion girth for 4 scions on each stock.

TABLE II

Mean differences between stock and scion girths in cm., adjusted for block differences.

	Scions ICS 1	ICS 45	ICS 60	ICS 95	Means
Stocks					
ICS 1 ...	—0.17	2.35	0.92	2.67	1.44
ICS 45 ...	—3.05	—0.32	—0.71	—0.29	—1.08
ICS 60 ...	—1.53	2.08	—0.37	1.45	0.41
ICS 95 ...	—1.39	0.67	—1.20	—0.38	—0.58
Means ...	—1.54	1.20	—0.34	0.88	0.05

L.S.D. 5% marginal means ±0.62.
L.S.D. 5% same row or column ±1.45.
L.S.D. 5% not in same row or column ±1.38.

With the individual stocks, on ICS 1 all scions show taper ; on ICS 60 only ICS 45 and 95 show taper ; on ICS 95 only ICS 45, and on ICS 45 all scions have overgrown.

Of interest is the rate of increase or decrease in the disparity of the union. This is shown most markedly by ICS 1 as a scion, the increase in stock-scion difference being almost linear on stocks of ICS 45, 60 and 95.

Yields. During the crop year 1st September, 1953, to 31st August, 1954, some of the trees bore their first crop and the yields are given in Table III.

TABLE III

Mean yields in gm. wet cacao/tree adjusted for block differences.

	Scions ICS 1	ICS 45	ICS 60	ICS 95	Means
Stocks					
ICS 1 ...	384	85	74	388	233
ICS 45 ...	519	—198*	568	522	353
ICS 60 ...	1,027	36	435	934	608
ICS 95 ...	247	124	297	534	301
Means ...	544	12	344	594	374

* An effect of adjustment.

L.S.D. 5% marginal means ±191.
L.S.D. 5% same row or column ±449.
L.S.D. 5% not in same row or column ±428.

The experimental error in these early yields is very high (coefficient of variation *circa* 60%) and this helps to account for the negative value for the yields of ICS 45 on 45 when adjusted for block differences. These yields are included in Fig. 2.

ICS 60 as a stock is significantly superior in promoting early yield to the other three clones as stocks, these not differing significantly among themselves.

As scions, however, both ICS 1 and 95 exceed ICS 60, and ICS 45 is significantly worse than all others. The best combination is ICS 1 on 60 followed by ICS 95 on 60. Both combinations have proved superior in early bearing to any of the clones as independent trees.

Discussion

When this experiment was started practically no information was available on stock scion relations in cacao apart from the fact that poor clones often gave better yields when budded on to unselected seedling stocks than when growing on their own roots (Dodds and Cope, 1951). The practical aim of this trial was, therefore, to investigate the importance of the stock in the performance of the scion on it and to find out whether a composite plant would be superior in yield to either the stock clone or the scion clone when grown as unworked plants.

For apples, Vyvyan and Maggs (1954) have summarised the nature of the growth information required and the progress towards obtaining it. When two clones with different growth rates are combined, the growth rate of the composite tree may bear no relation to either that of the scion or stock clone when these are grown as independent trees ; or, on the other hand, the resultant rate may be determined by the respective growth rates of the stock and scion when independent. This point has been investigated using girth as a function of growth rate. The results in Table IV have been obtained by comparing the mean stock girth of the self combinations 1/1 and 45/45 with the mean of the reciprocal grafts 1/45 and 45/1, *i.e.*, $\frac{22.3+15.4}{2}$ compared with $\frac{18.9+19.4}{2}$.

TABLE IV

Stock girths, in cm., for means of individual clones and their combinations.

Comparison	Self Mean	Combination Mean	Difference
1 and 45	18.9	19.1	0.2
1 „ 60	23.4	23.5	0.1
1 „ 95	21.5	22.4	0.9
45 „ 60	20.0	22.4	2.4
45 „ 95	18.0	18.8	0.8
60 „ 95	22.6	23.6	1.0

With the exception of the 45 and 60 comparison, all others show good agreement between the stock girths of the combined plants and the individual clones. The means for the combined plants are slightly higher as compared with the results with apples where they were a little lower. It seems reasonable to assume, therefore, that, as Vyvyan has suggested, some mutual mechanism exists regulating their respective growth rates.

In these combinations it is necessary to examine the respective importance of stock and scion, i.e., which plays the greater part in regulating the growth of the composite plant. In Table V the six comparisons between clones have been made by taking the less vigorous clone as the basis of comparison and calculating the percentage increase in stock and scion girth when the more vigorous clone is substituted as stock—second column, or scion—third column. The last column shows the stock and scion girth of the more vigorous clone as a percentage of the less vigorous.

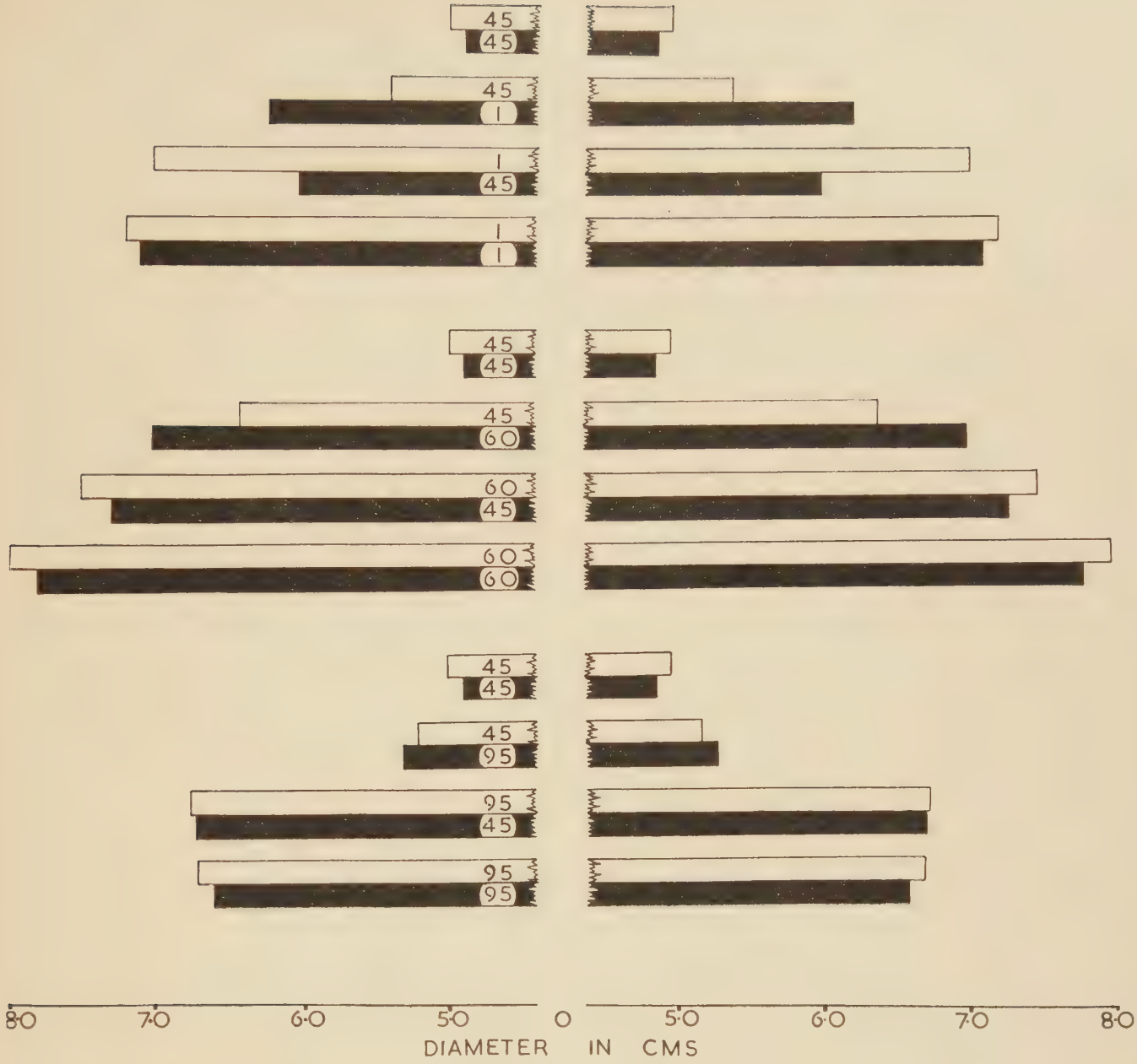

FIGURE 4

Diagrammatic section at graft union of ICS 45 with ICS 1, 60 and 95, white section indicates scion, black section stock.

To aid in the interpretation of these relations, Fig. 4 shows the comparisons of ICS 45 with the other three clones. This figure may be considered as a longitudinal section at the graft union. Taking the 45 and 60 comparison it is clear that, starting with 45 45, changing the scion to 60 results in greater girths of stock and scion than results in changing the stock from 45 to 60. Similarly for the other comparisons. ICS 1 appears to give some anomalous results, but in general the effect of a clone on growth as measured by girth is greater as a scion than as a stock.

That the relations, however, are not similar in the different combinations can be seen in Fig. 4. In the 45 and 60 comparison, the vigorous 60 swings the balance in favour of 60 in whatever manner it enters the combination, i.e., either as scion or stock in regard to 45. In the 45 and 95 comparison, however, this is not the case, 95 producing its effect only as a scion.

This is the type of comparison for which Vyvyan and Maggs had planned a similar experiment. Is the difference in growth of two varieties when used as scions the same irrespective of rootstock? And conversely is the difference the same when they are used as stock irrespective of the variety used as scion? The comparisons are of the form: 1/45-60/45 against 1/95-60/95, *i.e.*, is the difference between 1 and 60 the same when grafted on 45 as when grafted on 95? These relations have been examined in regard to stock and scion girths, disparity of union and

yield. The results are in general inconclusive, some comparisons showing good agreement, others showing none. The questions must, therefore, be answered in the negative for cacao, the stock scion interaction being different with different clones.

TABLE V

Percentage increase in stock and scion girth for the pairs of combinations of clones.

Comparison		Girths as % of less vigorous clone			
		45/45	45/1	1/45	1/1
45 and 1	Scion girth	100	109	140	143
	Stock girth	100	126	122	145
		45/45	45/60	60/45	60/60
45 and 60	Scion girth	100	127	150	159
	Stock girth	100	143	149	160
		45/45	45/95	95/45	95/95
45 and 95	Scion girth	100	103	135	133
	Stock girth	100	109	135	133
		95/95	95/1	1/95	1/1
95 and 1	Scion girth	100	102	105	107
	Stock girth	100	117	100	108
		95/95	95/60	60/95	60/60
95 and 60	Scion girth	100	101	123	119
	Stock girth	100	110	119	119
		1/1	1/60	60/1	60/60
1 and 60	Scion girth	100	101	110	111
	Stock girth	100	96	115	110

As regards yields, an important point to be investigated was the relationship, if any, between yield and the growth of the tree as measured by its girth. At this stage the correlation coefficient proved small and non-significant. Girth size, therefore, is no measure of early yield. Had it been so it would have proved a useful criterion of the potential value of any combination. The point will be checked with future crop returns, however.

The various relations tested for girth measurements have been repeated for yields. In all cases the mean yields of the grafts have considerably exceeded the mean yields of the separate components, but further data must be accumulated before much reliance can be placed on these early yields.

When such further data are available the practical importance of clonal stock scion combinations can be assessed. ICS 1, 60 and 95 are all potential high yielding clones, but no single one is ideal. ICS 1 while being fairly resistant to Witches' broom disease is not tolerant of heavy soils with impeded drainage. ICS 60 does reasonably well under such conditions, but is very susceptible, vegetatively, to Witches' broom. The combination of ICS 1 on ICS 60 may, therefore, be a possibility on heavy soils in Witches' broom areas. ICS 95 is probably the best general purpose clone available at present being tolerant of a wide range of soil conditions and not very susceptible to Witches' broom. Mono-clonal plantings are not to be recommended, however, particularly in regard to flavour characteristics of the final product. Less hardy clones like ICS 45, a criollo type, may impart such desirable flavour characteristics if better yields can be secured on more vigorous rootstocks. There is the possibility of improving the performance of many of the ICS clones which on their own roots are poor yielders. If these clones can be improved by budding or grafting on to more vigorous clonal stocks such as ICS 60 the utilisable range of the ICS clones becomes much wider. It will then be necessary to make a more comprehensive search for good stocks and stock-scion combinations.

Summary

(1) In a stock-scion experiment with cacao involving four clones as stock and scion in all combinations, the stock and scion girths have been used to investigate the early growth of the various combinations.

(2) In general, a clone produces a greater effect on growth when used as a scion than when used as a stock.

(3) No simple pattern of behaviour exists between the various combinations, the stock-scion interactions varying with the different clones.

(4) Early yields are influenced by both stock and scion but bear no relation to the girth of either stock or scion.

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Periodicity of Cropping in Young Cacao Cuttings

by

D. B. Murray

In Trinidad, the main cacao crop from mature trees is harvested from November to January, i.e., at the end of the rainy season and the late crop in May and June at the end of the dry season. It has been observed, however, that cuttings on first coming into bearing tend to produce most of their crop in the May-June period giving little, if any, December crop.

The first two clonal trials, CRB 1 and CRB 2, planted at River Estate in 1937 and 1938 both contain ICS 1. In Table I is given the distribution of the total annual crop for this clone between the main crop period taken as September to March and the late crop period, April to August.

Table I

Crop harvested in period April to August as percentage of total annual crop at different ages from planting.

	ICS 1, CRB 1		ICS 1, CRB 2	
Years from planting	Total crop pods/tree	Late crop % total	Total crop pods/tree	Late crop % total
2	—	—	0.1	100
3	7.2	100	2.8	84
4	7.3	100	22.2	93
5	23.5	72	7.4	41
6	28.4	68	29.8	36
7	28.2	57	17.0	38
8	17.4	29	10.3	30
9	11.9	19	22.0	3
10	24.1	6	18.0	21
11	17.3	40	27.6	9
12	26.5	11	—	—

The total annual crop shows considerable seasonal variation, but the progressive decline with age of the proportion of crop borne in May and June is obvious. This change in periodicity must evidently be borne in mind when comparing annual cropping at different ages. In CRB 1, for example, the total crop at 5 years and 10 years is almost identical. At 5 years, however, 72% of the crop was harvested as late crop whereas at 10 years of age only 6%. Similarly for CRB 2 at 4 and 9 years. In making such a comparison as average weight of beans per pod, merely to divide total annual weight of beans by number of pods will not give a valid comparison since pods developing in the dry season give a smaller weight of beans per pod than pods developing in the wet season. This explains the apparent low pod values for ICS 1 in its early years as compared with the original selection and the increase in the value with time as noted by Cheesman (1946).

This change in cropping periodicity with age differentiates cacao from such other tropical tree crops as citrus, mango, avocado which, in Trinidad, flower and fruit at much the same time of year in regard to wet and dry season irrespective of age.

In cacao, one environmental factor concerned in this periodicity is intensity of shade. The data in Table II is taken from a shade experiment with cacao (Murray, 1954).

Table II

Late crop as percentage of total crop for plants growing under different light intensities.

	1952-53		1953-54	
Light intensity % full light	Total crop pods/plot	Late crop % total	Total crop pods/plot	Late crop % total
15	120	82	293	63
25	224	94	333	64
50	417	98	368	63
75	417	98	237	75
100	330	100	450	96

Light intensity is evidently of greater importance than physical age, heavily shaded plants producing a greater proportion of crop in the December period than unshaded plants of the same age.

The physiological basis for these observations must involve the fundamental question—does cacao need a period of adverse conditions to stimulate flowering and fruiting or does it combine vegetative and reproductive functions best under a completely uniform environment?

It is a matter of observation that the absence of a December crop in the early years is not due to failure of flowering or setting. The young pods that set in August and September are, however, lost through severe cherelle wilt. Only flowers setting in January and February bring their pods through to maturity in May and June.

If correlation between vegetative and reproductive growth is explainable on the basis of auxin controlled food competition, it is suggested that in young plants vegetative growth in the wet season is so rapid that in the competition for nutrients the young fruit are lost. As the dry season

advances water stress develops and differentiation to the reproductive state is favoured. Young pods meet less vegetative competition and stand a chance of reaching maturity. With increasing size of plant, relative vegetative growth slows down, and the tree matures its main crop at the end of the rainy season.

Further information on growth and cropping is required from a wider range of environmental conditions that exist in Trinidad. It is unlikely, however, that field observations alone can establish a physiological basis for the phenomenon, the ideal requirement being an artificially controllable environment under glasshouse conditions.

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An Anti-transpirant for Cacao

GOODRITE Latex VL-600 (*) is a modified vinyl resin which when diluted with water and sprayed on the leaves of a plant dries to form a colourless transparent film which, it is claimed, reduces water loss without any phytotoxic effects.

The first trial made during a dry spell in the rainy season was vitiated by rain the day after planting, both treated plants and controls giving 100% survival. At the concentration of 20% which was used there was, however, no evidence of phytotoxicity except in the case of very young flush leaves and the film seemed very persistent. A later trial, planted in the dry season without shade, showed that treated plants survived longer and lost their leaves later than untreated plants.

While there can be no substitute for good conditions at planting, VL-600 may prove of use with valuable clonal material in helping the plant to survive a short spell of dry conditions.

It has been employed also in the shipment of bare rooted cuttings and in establishing rooted cuttings from propagators.

D. B. Murray.

* Sample supplied by B.F. Goodrich Chemical Co., Cleveland, Ohio, U.S.A.

The Effect of Maleic Hydrazide Sprays on Cacao Seedlings and Rooted Cuttings

by

D. B. Murray and R. Nichols

In the course of investigations on hormone levels in cacao, a trial was undertaken of the effect of maleic hydrazide sprays on the growth of young seedlings and rooted cuttings. Maleic hydrazide has been shown to inhibit growth in many plants, the actual mechanism of its action still not being thoroughly understood. Greulach and Haesloop (1954) deal with some of the evidence that it acts as an anti-mitotic, i.e., as an inhibitor of cell division rather than as an anti-auxin or inhibitor of cell expansion as suggested by Leopold and Klein (1952).

Experimental Details

A batch of 25 seedlings growing in baskets was selected for uniformity and arranged in a 5×5 Latin square. Treatments were: (1) water spray, (2) maleic hydrazide spray at 0.05%, (3) 0.1%, (4) 0.2% and (5) 0.4%. The maleic hydrazide solution was adjusted to pH 5.5 and Teepol was used as a spreader. Using a spray gun, the upper and lower surfaces of the leaves were sprayed on 13th July, 1954, and again on 30th August, 1954. A similar batch of 25 rooted cuttings of the clone ICS 60 was treated in the same way. Measurements were made periodically of the height of the seedlings and the numbers of leaves on the seedlings and cuttings.

Experimental Results

In the seedlings, very marked growth inhibitory effects were produced, see Table I.

TABLE I

Average increase in height and number of leaves during the period 13th July to 13th October, 1954, of seedlings receiving different concentrations of maleic hydrazide.

Maleic hydrazide concentration %	Height increase (cm.)	Increase in number of leaves
0	8.2	4.8
0.05	4.5	4.8
0.1	1.2	0
0.2	0.6	—1.0
0.4	0.8	—0.6

FIGURE 1

Effect on seedlings of maleic hydrazide sprays at concentrations of l. to r. control, 0.05%, 0.1%, 0.2%, 0.4%.

Fig. 1 shows the plants at the end of the three-month period. Besides the inhibition of growth, maleic hydrazide at concentrations of 0.1% and higher resulted in loss of apical dominance and subsequent development of lateral buds as may be seen in the photograph. Some toxicity occurred at 0.2% and 0.4% leading to loss of leaf, but no morphological effects on leaf shape were observed.

This is in contrast to the response of the cuttings where very little inhibition of growth was found. Height of the cuttings was not measured as some had already branched and Table II shows no significant effect on leaf production.

TABLE II

Average increase in number of leaves during the period 13th July to 13th October, 1954, of rooted cuttings receiving different concentration of maleic hydrazide.

Maleic hydrazide concentration %	Increase in number of leaves
0	10.2
0.05	10.0
0.1	12.4
0.2	9.8
0.4	9.8

However, several of the plants receiving the higher concentrations exhibited morphological aberrations in the leaves of the new flush. The leaves were narrow and twisted, an extreme case being shown in Fig. 2. Leaves of similar shape have been produced in sand cultures deficient in zinc. These leaves resemble the "frenched" leaves of tobacco that result from maleic hydrazide treatment and this type of leaf with its distorted veins is associated with hormone unbalance.

Conclusion

The morphological effects of maleic hydrazide appear to differ in seedlings and cuttings. In the former it would seem to act as an anti-mitotic inhibiting the development of the terminal flush of leaves. In cuttings, on the other hand, the morphological abnormalities point to an anti-hormone effect. Further work is necessary before the significance of these effects can be explained.

FIGURE 2

Abnormal leaf resulting from maleic hydrazide treatment, left, normal leaf, right.

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Disinfestation of Rooted Cacao Cuttings

by

R. G. Fennah

ROOTED cacao cuttings, if handled by the propagation methods now standard in Trinidad, and dispatched as soon as they are ready, are virtually free from insects. If, as often happens, they have to be held in the hardening shed longer than is absolutely necessary they may become lightly infested with aphids (*Toxoptera*), mealy-bugs (usually *Pseudococcus citri*), and, much less commonly, with the armoured scale-insects *Asterolecanium pustulans* (the fringed scale) and *Howardia biclavis* (the burrowing scale). In addition the leaves may be attacked by two species of Aleyrodidæ (white flies) and red scale (*Selenaspidus*), together with one or two incident jassids or membracids. The potting soil is free from insect pests : it frequently harbours small millipedes, which feed on organic matter and rotting debris, and may also contain a small colony of ants if the cacao is infested with mealybugs.

Successful methods for the shipment of rooted cuttings by sea and air have been described (Evans, 1951 : 202). For shipment by sea, cuttings, rooted in a suitable medium, are packed in Wardian cases ; for transport by air the plants, with their roots encased in moist sterile sawdust held in hessian bags, are packed in cardboard cartons : they may be sent even with their roots bare. Whichever method is used, the cuttings, at the time of dispatch, are in a condition of active growth : they are moist and may have a relatively large part of their total leaves in an immature state, and in addition they may have buds which are beginning to expand.

The disinfestation of such material prior to dispatch calls for the use of fumigants.

It is a matter of no difficulty to destroy most insects that are exposed on the plant by means of a contact insecticide, such as a spray comprising 1.5% white oil emulsion and 0.007% parathion. Unfortunately, such treatment leaves unscathed any insects which may be ensconced in sheltered situations, and among such insects are various stages of the mealybugs and stem-attacking armoured scales mentioned above. These can be killed only by systematic insecticides or by fumigants. The use of a systematic insecticide for this purpose has not so far been investigated : the unpredictability of the rate of its uptake by the plant, its phytotoxicity if too high and its insecticidal inefficiency if too low pose a problem of controlling application which is far more difficult than any attending the administration of a fumigant treatment.

Consideration of fumigants was extended in the present investigation to include BHC evolved by a smoke generator. This forms a dense fog of particles of contact insecticide : the material itself is generally considered to have a slight fumigant action in small confined spaces.

A single test was made in which four healthy rooted cuttings, which were free from insects, and three newly-picked cacao-pods, each with the valleys encrusted with several hundreds of mature mealybugs (*Pseudococcus citri*) and innumerable crawlers and unhatched eggs, were exposed at a temperature of 87° and a relative humidity of about 82% in a sealed chest of 6.75 cubic feet capacity to the smoke produced by the ignition of a 13.5 gm. cartridge of BHC. The time of exposure was 2 hours, sufficient to allow the fog to settle. The cuttings and the pods were removed immediately afterwards : the former were placed under shade of medium density among cacao in the field ; the latter were transferred to the laboratory.

The results were decisive. The smoke deposit had settled mostly on the upper side of the pods to produce a grey " bloom." In no part of the pods were any dead mealybugs noted, apart from a few crawlers. The pods were kept under daily observation until they began to become discoloured, a period of six days. In this time the number of crawlers increased and new areas of the pod-surface were invaded. Newly-hatched young were seen throughout the period of observation.

In contrast to the negligible response on the part of the insects to the presence of the smoke dust, the reaction of the plants was striking. Within less than forty-eight hours the mature leaves assumed a pale khaki hue and were abscissed a day or two later (cf. Fig. 1). One terminal bud partly expanded and abscissed its foliage while the leaves were less than an inch long. Some days later axillary buds lower on the stem began to sprout, but failed to extend.

It was abundantly clear the BHC smoke generators cannot be used in the conditions described to disinfest cuttings without causing severe injury.

The fumigants tested were limited to two of the most easily obtained and stored, hydrocyanic acid gas and methyl bromide. The first was applied to the floor of the chamber in the form of a powder which on exposure to moist air gives off 20% by weight of HCN (" Cymag " manufactured by Plant Protection, Ltd.) and the second as a gas liberated by fracture of a glass capsule containing the liquid. The standard capsule available contained 20 ml. of methyl bromide and a supply was kindly provided by the Department of Agriculture from a sample donated by Tedlee Chemical Corporation of Brooklyn, N.Y.

A few capsules of 6.6 ml. were prepared from these by the Department of Sugar Technology. The fumigating chamber consisted of a hardwood chest of 6.75 cubic feet

capacity. This held 18 rooted cuttings when filled. All seams were lined with several layers of gummed paper and the junction of the lid and base was similarly sealed after closure.

After fumigation each plant was kept under observation until the final effect of the treatment could be assessed.

Fumigation with HCN

Fumigation was carried out at a relative humidity of over 80% and at temperatures close to 85° for the shorter exposures and varying between 75° and 88° for the longer. The results for a range of treatments are given in Tables I and II with dosages converted to standard volumes. In Table I the percentages quoted under the heading millipedes and jassids are based on extremely low infestation figures. Mealybugs were present on the rooted cuttings only in low numbers, and the percentages are based not on these but on mealybugs introduced into the chamber on infested cacao-pods. A dash entered in a column means that no observations were possible with the material used. The rooted cuttings comprised ICS 48, SCA 12 and a range of seedlings of Colombian origin.

TABLE I

Percentage kill of insects and other arthropods after fumigation with HCN for 24 hours.

HCN gm. per 1,000 cu. ft.	Mealy-bugs	Jas-sids	*Asterolecanium*		Milli-pedes	Ants	Aphids
			Eggs	Craw-lers			
2.96	30	—	0	0	0	—	—
5.92	—	—	—	—	0	—	100
11.84	—	—	40	77	0	—	100
17.76	100	—	88	100	—	100	—
23.68	100	—	100	100	—	100	—
29.60	100	100	100	100	70	—	—
59.20	—	—	—	—	100*	—	—

* Seventy millipedes inserted for the test.

A test was made using 29.60 gm. of HCN for 12 hours within the temperatures and humidities given above. The percentage kill obtained was as follows : mealybugs, 100 ; jassids, 100 (15 specimens only) ; *Asterolecanium* eggs, 30, crawlers, 74 ; millipedes, 50 (22 specimens) ; ants, 100.

The effect of these treatments on the leaves of the plants is as follows. Exposure for 24 hours to dosages of HCN up to and including 29.6 gm. per 1,000 cubic feet produced no injury on leaves or buds. Exposure for the same period to a dosage of 59.2 gm. per 1,000 cubic feet resulted in death of flowers and discoloration of the lamina between veins and around wounds on younger leaves, but little obvious change in old leaves. A dosage of 88.8 gm. per 1,000 cubic feet caused rapid collapse of young foliage, and abscission of all other leaves within a few days. The plants apparently contained sufficient reserves to support the development of new shoots from axillary buds, and ultimately recovered. The plants which were exposed to 29.6 gm. of HCN per 1,000 cubic feet for 12 hours sustained no injury.

Fumigation with Methyl Bromide

(*a*) Methyl bromide ml. per 1,000 cu. ft. 978

Time of exposure in minutes	% Mortality					Phytotoxic effect
	Mealy-bugs	Jas-sids	Milli-pedes	Aphids	Ants	
60	0	0	0	0	—	nil
100	100	100	100	100	—	plants defoliated, subsequently died

(*b*) Methyl bromide ml. per 1,000 cu. ft. 2,934

Time of exposure in minutes					
5	0	0	0	0	nil
15	100	100	100	100	young growth injured, plants recovered
17	—	—	—	—	plants defoliated, subsequently died
20	—	—	—	—	flowers, leaves and roots killed

Exposures of 25, 30 and 60 minutes were also made with the same result as for the 20-minute exposure.

Discussion

The aims of the investigation were to ascertain the lowest effective dosage for insecticidal purposes, and to estimate whether there exists a gap between this dosage and the lowest dosage at which the fumigant causes injury to the plants.

It is evident that a dosage close to 30 gm. HCN per 1,000 cubic feet is insecticidally effective and not seriously phytotoxic in the fumigating conditions used. At 60 gm. HCN per 1,000 cubic feet all arthropods are killed, but some damage is sustained by the plant. Above this level injury to the plant is severe though not necessarily lethal even at a dosage of 88 gm. HCN per 1,000 cubic feet.

It must be stressed, however, that any treatment which leads to defoliation of a rooted cacao cutting must be regarded as gravely injurious. The low level of food reserves in such plants may, and, indeed, frequently does, preclude any chance of recovery if the leaves are abscissed.

The dosages of methyl bromide employed, by reason of the limited facilities available, were heavy, and it is not surprising that the time factor in such circumstances is of critical importance. It is obvious that it would be more convenient to use a larger fumigating chamber. The important fact, however, is largely independent of such considerations, and is simply that only a narrow gap exists between toxic level to invertebrates and the threshold of damage to the plants. A dosage of 2,934 ml. to 1,000

cubic feet (about 11.5 lb. per 1,000 cubic feet) appears to be effective and relatively safe in a treatment lasting a little less than fifteen minutes. At one-third of this dosage the data suggest that an exposure-time of about eighty minutes might prove satisfactory.

FIGURES 1 AND 2

(*left*) Leaf damaged by BHC " smoke." The dark areas represent the normal green colour of the leaf, while the damaged area, of a pale khaki hue, is represented by the general light grey tint.

(*right*) Leaf damaged by HCN. The damaged areas are almost black, the areas of middle-tone are the normal green, and some of the veins are narrowly margined with golden yellow.

When leaf tissue has been injured by fumigation the symptoms may take some days to develop. The tissues most susceptible to injury are newly-opened buds and flowers. These wilt and die within a few hours. Next in order of sensitivity come expanding leaves, followed by fully-expanded but still immature leaves, and buds enclosed in a cluster of stipules, and finally, by mature leaves and apparently roots. The youngest leaves become flaccid within two or three hours, and all affected leaf tissue darkens in colour within a day. Mature foliage assumes a hue that is almost bottle-green before the leaves are shed. If damage is restricted to part of a leaf, the injured area darkens until it is almost black (Fig. 2).

Summary

Fumigant treatment of rooted cacao cuttings at 30 gm. HCN per 1,000 cubic feet at temperatures ranging between 86° and 89° and a relative humidity of 80-100% for 24 hours gave complete kill of insects and caused no damage to the plants. At a dosage of 60 gm. all arthropods were killed and some leaves were injured. Above this level leaf injury was severe. Methyl bromide at 2,934 ml. to 1,000 cubic feet in a 15-minute treatment was effective against arthropods and caused only slight foliar injury. Longer exposures were seriously phytotoxic.

Of other treatments tried for the purpose of disinfestation the use of BHC smoke generators failed to give control of mealybugs (*Pseudococcus*) at a level which caused defoliation of the cuttings. Contact sprays of white oil and parathion (1.5% plus 0.007% respectively) were effective against insects which they happened to reach and were not phytotoxic, but were ineffective against *Pseudococcus* and diaspine scale-insects in concealment.

Reference

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A Test for Resistance to *Marasmius perniciosus* Stahel

by

Paul Holliday

The breeding for resistance to Witches' broom disease of cacao *Marasmius perniciosus* Stahel has made it necessary to devise a method for inoculating the host plant with the parasite. The method must be such that no plants tested will escape infection, but at the same time it must not be so severe as to break down true resistance in the host. An adequate supply of inoculum and a simple and rapid means of applying it, under uniform conditions, are essential.

Inoculation methods previously used in studies on the disease (Stahel 1919, Stell 1928, Briton-Jones and Cheesman 1931, Baker and Crowdy 1943, Baker and McKee 1943, and Dale 1946) were unsatisfactory for testing resistance. They involved the use of well grown plants under field conditions with results that were so variable that some susceptible tissue certainly escaped infection. Desrosiers *et al.* (1954) inoculated 20-day old seedlings and obtained a 71% infection rate.

The inoculation technique used in the test to be described has been developed from a method reported—but not in detail—from Ecuador (Anon. 1950). The test has already been briefly referred to by Holliday (1954a).

Inoculation of Young Cuttings and Seedlings

Baker and Crowdy (*loc. cit.*) showed that infection was obtained most readily on young breaking vegetative buds and when rain fell at the time of inoculation. Their simple and rapid method was used for obtaining suspensions of basidiospores for inoculation. Inoculum was applied with a small brush to buds of young plants in the greenhouse. The plants were then mist-sprayed with tap water for varying intervals of 2-9 hours.

Results were variable. Only 40% success was obtained with seedlings 7-9 weeks old. Increasing the spraying time after inoculation above 4 hours did not significantly increase the percentage of success. Inoculation of seedlings in the two-leaf stage gave a 60% infection rate.

Seedlings were more readily infected than cuttings. This was probably due to the presence of a relatively more vigorous and continually growing terminal bud. There was a marked lowering of success with cuttings if their buds failed to break within 10 days of inoculation. It was not possible to predict whether a bud would have developed normally within this period. Neither spore germination nor spore concentration within the limits used affected the results. Since water conditions were not considered limiting, the escape from infection shown by a high proportion of susceptible plants was probably due to uncontrollable factors inherent in plants of this age.

Although, therefore, typical symptoms were readily reproduced on young plants in the greenhouse—for the first time in Trinidad—the method could only have a very limited application in testing for resistance.

Inoculation of Germinating Seedlings

In preliminary experiments the testa was removed from ripe seed which was then germinated in damp dishes. After 7 days the seedlings were inoculated by dipping them into a spore suspension and were then planted out in cacao baskets. All the plants became infected and death of the majority occurred after two months. It was necessary to remove the testa because it cannot be penetrated by the germ tube and removal also hastens germination. The results showed that a 100% infection rate could be readily obtained using this method.

Some Conditions for Certain Infection

Before this method of inoculating germinating seedlings could be tested against resistant material it was necessary to standardise certain procedures in its use. The following inoculating technique was used. The testa with accompanying mucilage was peeled from ripe, open pollinated seed of the clone ICS 1. The beans were then germinated in glass dishes, which were kept damp with filter paper, in the laboratory. A fresh spore suspension in glass-distilled water was prepared and the seedlings dipped into it after they had been left to germinate for the required time. Inoculations were carried out about 2200 hours because sufficient spores are only available then. The sporophores do not begin spore deposition until dusk. After inoculation, the seedlings were immediately planted in cacao baskets (filled with the standard College potting mixture, Evans 1953) just below the surface of the soil which had previously been watered. They were grown under open greenhouse conditions.

At 7 days germinating seedlings were too well grown to be handled without risk of damage to the roots. Seedlings of three different age groups (A, B and C) were, therefore, inoculated (Table I).

(A) 6-12 hours. The radicle had begun to emerge and was up to 0.4 cm. long. The cotyledons had not visibly begun to separate and the transparent inner integument covering them was virtually intact.

(B) 50-60 hours. The radicle was 1-2 cm. long and the cotyledon folds were opening. The inner integument had ruptured.

(C) 100-110 hours. The radicle was 4-5 cm. long and the first lateral rootlets were clearly visible. The cotyledons were not completely separated. The hairy, colourless plumule was just visible, 1 mm. in length.

TABLE I

Infection of germinating seedlings of different ages.

Age group	Inoculated	% Infected	Incubation (mean days)
A. 6-12 hours ...	75	18.7	43
B. 50-60 hours ...	70	64.3	24
C. 100-110 hours ...	73	100.0	19

Inoculation at least 4 days (age group 100-110 hours) after extraction from the ripe pod and removal of the testa showed that no susceptible plant escaped infection. The lowering of the incubation time with increasing age of the seedling was probably due to several factors. The older seedlings had more susceptible tissue exposed, infection took place at more points than on the younger seedlings, and, therefore, symptoms developed more quickly. The initial rate of growth of the 4-day old seedlings after inoculation was also greater and, from previous experience in the field, it was known that a vigorously developing infected shoot will tend to show symptoms earlier than a slowly growing one. Further, the more advanced older seedlings developed more rapidly in the baskets after inoculation and observations on the appearance of symptoms could begin sooner.

Previous seedling inoculations had been carried out with high spore concentrations. The lower limit of concentration was, therefore, determined. Seedlings, 4 days old (100-110 hours), were inoculated as before. The results are given in Table II.

TABLE II

Infection with varying basidiospore concentrations.

Concentration (thousands per cc.)	Inoculated	% Infected	Incubation (mean days)	Death (mean days) %	
180-220	60	100	19	64	80
90-110	60	100	18	64	51
40-50	60	90	24	68	42
20-25	60	71	25	76	25
10-12	30	63	25	66	14
5-6	60	53	27	73	9
1-2	30	20	27	71	3

A minimum concentration of about 100,000 spores per cc. was necessary for certain infection. Below this the percentage of plants infected and finally killed decreased progressively. There was no important effect on the incubation time or on the number of days after which death occurred. The 80% death rate at a concentration of 180,000-220,000 spores per cc. may be compared with the figure of 81.5% for ICS 1 selfed seed obtained with a spore concentration twice as great (Table III). It was likely, therefore, that a concentration of about 200,000 imposed a sufficiently severe and adequate test.

It was possible that the length of the period of immersion in the inoculum might have some effect on uniformity of the results. At a concentration of 180,000-220,000 spores per cc. 4-days old seedlings were inoculated by immersing them in the spore suspension for three different time intervals: half a minute, 1 hour and 9 hours. All treatments gave a 100% infection rate. There were no differences in the incubation time or in the number of days after which death occurred. The more rapid quick dip method should, therefore, be used.

Symptoms

The first signs of infection of susceptible seedlings inoculated when 4-5 days old were slight swellings on the lower part of the stem near ground level or where the cotyledons arise. On some plants they began to appear 9 days after inoculation. The mean incubation in a very susceptible cross being 19 days. Eventually nearly all plants exhibited symptoms at both sites, but those at the base of the stem commonly appeared 4-5 days sooner than those at the cotyledons. Small shoots usually developed at the cotyledon node—this rarely happened in a healthy plant—growing up to 7 cm. in length and up to nine in number. The node increased in diameter to sometimes more than twice normal size. The cotyledons became persistent. Hypertrophy of the lower part of the stem was most severe at ground level, but it may extend downwards to the first lateral roots and upwards to the cotyledons. At 6-8 weeks symptoms were well developed (Fig. 1). Necrosis of the infected parts began soon

FIGURE 1

8-week-old plants from open pollinated seed of ICS 1 inoculated when 4 days old. (A) Not inoculated. (B) Most severe symptoms at the cotyledons. (C) Most severe symptoms at the base of the stem.

afterwards and the most susceptible plants died within five weeks.

The infected seedling was comparable to a grown-through broom in the field, i.e., there was healthy tissue both above and below the diseased parts. A seedling which was older than 4 days when inoculated sometimes showed a different symptom pattern, for the terminal bud often became infected. The symptom pattern, as has been noted in the field, was dependent on the host's growth rate and on the stage of growth reached when infection occurred. The relatively more rapidly growing parts grew away from infection and became symptom free whilst those in which growth was much slower became infected. In the 4-days old seedling the latter parts are the base of the plumule, i.e., the cotyledon node, and the base of the hypocotyl. Fortunately, *Theobroma cacao* is epigeal so that symptoms could be inspected readily without disturbing the seedling. It is important, therefore, that all seedlings should be of the same age when inoculated so that the symptom picture is not confused.

Resistance

Some Amazonian forastero trees introduced by Pound (1938) exhibit high resistance to Witches' broom disease. Examination of field records, kept by the Department of Agriculture, indicated that trees in the groups known as SCA and IMC were amongst the most resistant. Progeny from 5 clones were tested : SCA 6, SCA 12, IMC 67, SP 1 and ICS 1. SCA 6 and SCA 12, from natural and artificial infection trials, are immune to vegetative infection and extremely highly resistant to pod infection. IMC 67 is less resistant than the two SCA clones, since it forms a few brooms, but it is less susceptible than the local Trinidad selection ICS 1. SP 1 came from Surinam where it was reported to be resistant but nothing was known of its field performance under Trinidad conditions.

Since the Amazon material is self sterile the clones were crossed with ICS 1 and compared with ICS 1 selfed seed. All seedlings were inoculated when just over four days old by the method already described. Seedlings from crosses between ICS 1 and SCA 6 and 12 are being tested in the field by relying on natural infection (Bartley 1953) but this method of testing had not previously been carried out. The results are shown in Table III.

Resistance was reflected in the presence, suppression, or absence of symptoms ; in the degree and development of hypertrophy ; in the period after which death occurred and in the number of deaths. The range of reaction to infection could hardly have been more extreme and striking. Some plants showed pronounced hypertrophy and necrosis, dying within five weeks ; whilst others could not be distinguished from the uninoculated controls.

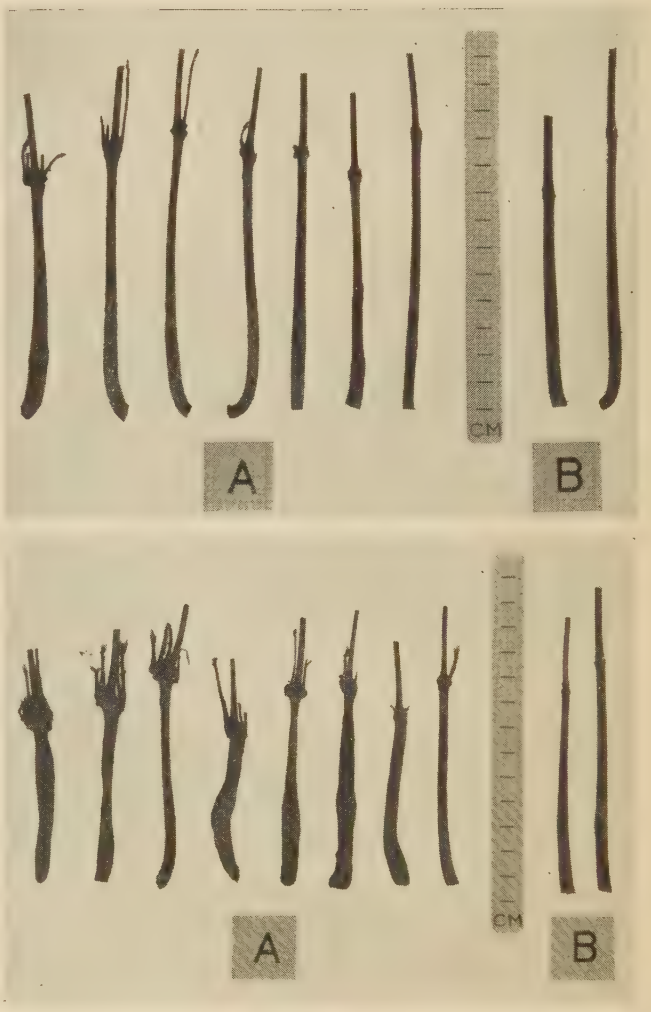

FIGURE 2

The parts of 8-week-old plants showing symptoms (A) inoculated when 4 days old. (B) Not inoculated. Top : A mainly resistant cross, ICS 1 × SCA 6. Bottom : A mainly susceptible cross, ICS 1 × ICS 1.

TABLE III

Infection of seedlings of known parentage

Cross	Inoculated	Incubation	% with symptoms		Death		
		Mean days	Initial	At 8 wks.	%	Range and Mean days	
ICS 1 × ICS 1	101	20	100.0	100.0	81.5	28–97	62
ICS 1 × SP 1	54	19	100.0	100.0	61.1	43–128	77
ICS 1 × IMC 67	101	23	100.0	99.1	40.6	35–167	84
SCA 12 × ICS 1	108	27	71.3	50.9	9.3	75–169	127
SCA 6 × ICS 1	111	25	68.5	52.3	0.0	—	—

The range of symptoms shown in a predominantly susceptible cross and in a predominantly resistant one is illustrated in Fig. 2. For photographing, the seedlings were removed from their baskets at eight weeks and the upper part of the stem and the root region, both symptomless, were cut off. The cotyledons were also removed.

Assessment

A preliminary assessment was made at eight weeks since by this time the most susceptible seedlings had begun to die and the degree of hypertrophy in comparison with healthy plants of the same age had reached a maximum. Two extreme groups were distinguished. One in which hypertrophy was severe, the leaves tended to become chlorotic and growth was slow. The other in which hypertrophy was slight or absent, there was no chlorosis and growth was almost normal.

A final assessment was made during the period of 4-6 months. This variable period was due to the differences in the time of death amongst the progeny. Generally, the more susceptible the cross the sooner could the final assessment be made. An attempt to obtain a completely quantitative measure of resistance by comparing the differences between degrees of hypertrophy was not wholly successful. This was because hypertrophy was influenced by the growth rate and vigour of the plant as well as by its inherent resistance. Although the degree of hypertrophy was not necessarily correlated with the degree of resistance in general it was.

All the progeny tested (Table III) were placed into one of the following four classes. The percentage within each class is shown in Table IV.

TABLE IV

Proportion of seedlings within each class expressed as percentages.

Cross	ICS 1 × ICS 1	ICS 1 × SP 1	ICS 1 × IMC 67	SCA 12 × ICS 1	SCA 6 × ICS 1
Class					
I	0	0	10	49	48
II	2	2	23	30	46
III	16	37	27	12	6
IV	82	61	40	9	0

I. Immune or highly resistant. II. Resistant.
III. Susceptible. IV. Highly susceptible.

CLASS I. Immune or highly resistant

Most plants showed symptoms which developed slowly ; some plants were symptomless. Hypertrophy was always slight and often at the base of the stem only. Necrosis was never severe and was limited to isolated patches in the cortex. The symptoms became less evident as growth continued. At 3-4 months few of the plants were distinguishable from healthy ones.

CLASS II. Resistant

All plants showed symptoms. Hypertrophy was rarely severe, but necrosis of the affected parts resulted in a check to normal growth. Leaf chlorosis was almost always absent. Excessive distortion and splitting of the cortex in the lower part of the stem sometimes occurred, but in many plants symptoms became less evident after eight weeks. Growth up to six months was appreciably slower than healthy plants, but death did not occur.

CLASS III. Susceptible

All plants showed symptoms and in the majority of cases hypertrophy was severe, sometimes exceeding twice the normal stem diameter. Leaf chlorosis was widespread and growth severely checked. Stem distortion was excessive and sometimes led to the development of gall-like outgrowths of the cortex. Plants were never more and usually less than half the height of healthy ones. Death during the period of six months in the greenhouse did not occur.

CLASS IV. Highly susceptible.

All plants showed symptoms. In some plants death was so rapid that severe hypertrophy did not occur. In others distortion of the stem was excessive. Growth was extremely slow and necrosis of the infected parts always led to death. The time of death after inoculation was variable, from 1.0-5.5 months, but usually within 2-3 months.

The limits of classes I and IV are clearly definable. The latter by death of the plant and the former by the absence of clear symptoms at the final assessment. The division between the intermediate classes II and III is less marked, but it is considered that this division is justified within the five crosses tested. In the cross ICS 1 × IMC 67, which had the most even distribution amongst the four classes, little difficulty was experienced in classifying classes II and III. The main differences between the two being the absence or presence of complete chlorosis and a large difference in growth rate (Fig. 3).

Table IV shows the differences in reaction to infection both within and between the crosses tested. Progeny with IMC 67 as one of the parents showed the most general distribution in the four classes. As a group they were more resistant than those derived from ICS 1 and SP 1, but less resistant than those from SCA 6 and SCA 12. An example of a plant in each class is shown in Fig. 3.

Discussion

The test is considered to fulfil the conditions required and laid down at the beginning. It was simplified by the fact that only one spore form of *M. perniciosus* had to be considered. Penetration by the germinating basidiospore is the only way natural infection is initiated. A possible disadvantage is that the pathogen has not been induced to sporulate in pure culture and, therefore, an ideally uniform source of inoculum was not obtained. Since, however, there is no clear evidence in Trinidad that strains of the fungus—differing in pathogenicity—occur, the use of a natural source of inoculum should give satisfactory results. The possibility of a strain effect was lessened by only using sporophores formed on brooms collected from one locality, the Santa Cruz valley. Inoculations should be made late in the evening since fresh spore suspensions can only be obtained then. The technique has shown its usefulness in a total of 2,899 inoculations made in the course of experiments not all reported here.

The test shows great promise in that any differences in susceptibility between seedlings and mature plants may be insignificant. In a tree crop this is of great importance

FIGURE 3

6-month-old plants from the cross ICS 1 × IMC 67 inoculated when 4 days old. I. Immune or highly resistant ; II. Resistant ; III. Susceptible ; IV. Highly susceptible ($2\frac{1}{2}$ months old). (C) Not inoculated.

since field tests are long and tedious. From field records ICS 1 was known to be more susceptible than IMC 67 and the latter clone more susceptible than both SCA 6 and SCA 12. The test confirmed this. Further field observations on 5-6-year-old trees which are the progeny from crosses made between three ICS clones and SCA 6 and SCA 12 (Bartley *loc. cit.*) indicate that trees in which SCA 6 was one parent are more resistant than those in which one parent was SCA 12. This observation was also confirmed by the test.

The first use of the test would be to enable a selection to be made, from any cross, of the most highly resistant plants before field plantings were undertaken. Secondly, it could be used to determine the extent of high resistance in Amazonian forastero trees. For example, the two groups PA and NA, also from Pound's collections, contain trees apparently as resistant as some of those in the IMC group. Thirdly, it was interesting to find that ICS 1 segregated resistant progeny. This confirms what was already known from field trials, namely, that this Trinitario clone is slightly resistant. It implies that the test may also be used for selecting for resistance within the Trinidad population as well, a population which is relatively susceptible when compared with some of Pound's upper Amazon types. For example, it might be found that the test applied to the selfed progeny of a highly susceptible Trinidad clone, such as ICS 36, would result in a 100% mortality rate. Whilst applied to selfed progeny of ICS 95, which is more resistant than ICS 1, valuable, resistant seedlings might be found. Fourthly, since heritable factors are clearly involved, studies in the inheritance of resistance should be facilitated by this inoculation technique. Finally, it may be used to extend our knowledge of the host range of the parasite and of the behaviour towards Witches' broom of any hybrids amongst the *Theobroma* species. Seedlings of *T. bicolor*, known to be susceptible as mature trees, were readily infected.

Penetration of the host by the spore germ tubes of *M. perniciosus* was reported by Stahel (1919) to occur only through the stomata. There are now indications that, provided suitably embryonic tissue is inoculated, penetration through the intact cuticle occurs. The correlation between pod and vegetative infection in most ICS clones suggests that the nature of resistance has a physiological basis (Holliday, 1954b). The behaviour of the most resistant seedlings, inoculated when 4 days old, indicated that their reaction to infection was one of hypersensitivity. A hypersensitive host plant is one which

reacts so quickly to invasion that the invaded cells are killed, the pathogen is unable to obtain nutriment and dies before serious infection can occur. This reaction towards an obligate fungus parasite, of which *Marasmius perniciosus* is an example, is typical of many plants resistant to them.

Summary

An inoculation technique with *Marasmius perniciosus* is described. The testa was removed from ripe cacao seed which was then placed to germinate in glass dishes kept moist with damp filter paper. On the fourth day after removal of the testa the seedlings were inoculated by dipping them momentarily into a freshly prepared suspension of basidiospores. Inoculation should be carried out late in the evening, since sufficient spores are only available then, and spore concentration should be adjusted to 200,000 per cc. Immediately after inoculation the seedlings were planted just below the surface of damp, standard potting mixture in small cacao baskets. They were kept in an open greenhouse.

On susceptible seedlings a constant 100% infection rate was regularly and readily obtained. The use of the technique on seedlings of known parentage from clones known to be highly resistant in the field showed that it selected for resistance. At 4-6 months the following assessment was made : Class I. Immune or highly resistant. Symptoms slight or absent, growth as healthy plants. Class II : Resistant. Symptoms moderate, growth retarded, little or no chlorosis. Class III. Susceptible. Symptoms severe, growth extremely slow, widespread chlorosis. Class IV. Highly susceptible. Symptoms very severe, followed by death.

The technique satisfied the requirements of a test for resistance. It was, therefore, considered that it will be of use in any breeding programme against Witches' broom disease and in studies of the inheritance of resistance. The test indicated that resistance is physiological and depends on hypersensitivity in the host plant.

Acknowledgments

I am indebted to Mr. F. W. Cope and Dr. B. G. Bartley for some of the seed from controlled pollinations.

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Notes on Minor Insect Pests of Cacao in Trinidad

PART 3. APHIDIDÆ

by

T. W. Kirkpatrick

Toxoptera aurantii (Boyer)

THIS is the only species of aphid commonly found on cacao in Trinidad. It is, as a rule, adequately controlled by the natural factors mentioned below and little or no damage is done ; occasionally, however, it may become abundant enough on a few trees to cause considerable distortion and wilting of flush leaves.

Description

Wingless viviparous female : Length, including cauda, 1.5-1.8 mm., breadth across widest part of abdomen 1.0 mm., cornicles 0.25 mm., slightly longer and more slender than cauda. Body dark brown or almost black, the abdomen with a reticulate sculpturing. Legs with the femora dark brown except at the base, tibiæ with basal five-sixths pale, apex of tibiæ and tarsi dark. Antennæ with the two short basal joints dark ; third pale ; fourth, fifth and basal part of sixth pale with dark apices ; terminal filament of sixth joint pale, about five times as long as basal part.

Winged viviparous female : Body, legs and antennæ very similar, but third antennal joint slightly darker and with a row of five circular sense-organs. Forewings about 2.25 mm. long, hyaline except for the conspicuous black stigma. Media vein with a single fork, the upper branch of which is slightly longer than the basal part.

Life History

Males are unknown and, as is usual with aphids in the tropics, reproduction is permanently parthenogenetic. The average number of young produced is about 20-25, at the rate of usually 4-6, though exceptionally as many as 11, each day for a period of 4-5 days. Smaller numbers than these are produced by solitary aphids probably because, as has been observed in other species (Ibbotson and Kennedy, 1950), crowding stimulates feeding and thus presumably increases the rate of reproduction. The wingless females become adult and start reproducing in as little as six days after birth, the alates in seven or eight days.

All stages feed on the underside of fairly young flush leaves and sometimes on succulent stems. Even before a leaf has noticeably hardened it becomes unsuitable and aphids feeding on such leaves die if they cannot move to a younger one. A colony on a single leaf may be of any size up to about a thousand individuals : unless there are at least a hundred or more, little or no visible damage is caused.

The proportion of alates to apterous females is very variable ; the wingless form usually predominates and many colonies contain no alates, but as many as 75% alates have on rare occasions been counted. The factors affecting wing production in aphids are not well understood : Rivnay (1937) working with *T. aurantii* in Palestine, concluded that a deficiency of water in their food, when the leaves were wilting on account of large numbers feeding on them, and a low atmospheric humidity, both tended to increase the proportion of alates produced. Observations in Trinidad show that there is a tendency for large colonies on rather older leaves to have a higher proportion of winged forms ; on the other hand, colonies with numerous alates seem to be commoner in the wet season. If it is correct that dry food tends to produce alates it would clearly be of biological advantage, for winged aphids have a much greater chance of finding a new food supply when their original one has become unsuitable.

When disturbed *T. aurantii* has a curious habit of waggling its abdomen in an anti-clockwise circular movement. All members of a colony do this in unison, several times at intervals of about one second. In a large colony an audible noise is produced, apparently by the heavily reticulated area on the abdomen near the cornicles rubbing against hairs on the hind tibiæ. It seems unlikely that either the movement or the noise can have much defensive value.

Natural Enemies

The most important predators are three species of Syrphid flies, *Baccha clavata* (F.), *B. dimidiata* (F.) and *B. gastrostacta* (Wied.), the slug-like larvæ of which are especially abundant during the dry season. According to Taylor (1952) a single larva of one of these Syrphids is capable, during the course of its developmental period of about one week, of exterminating a colony of aphids consisting initially of 20 individuals, and all the offspring produced by them. The larva of *B. dimidiata* is parasitised by an Encyrtid, *Syrphophagus* sp., and the pupæ of *B. dimidiata* and *B. clavata* by a Pteromalid, *Zatropis* sp. The larvæ of all three species are liable to attack by an entomogenous fungus, particularly during the rainy season.

Predators of rather less importance include the larvæ and adults of several species of Coccinellidæ (ladybird beetles) and the larvæ of Chrysopidæ (green lace-wing flies).

No hymenopterous parasite of any species of aphid has been recorded from Trinidad. *T. aurantii* is, however, attacked by an interesting Cecidomyid endoparasite

recently described by Barnes (1954) as *Pseudendaphis maculans* sp. n. An account of its life history has been given by Kirkpatrick (1954) so a brief summary will suffice here. Only a single midge larva develops in each aphid and it becomes fully fed after 6-7 days. It then leaves the host, which dies almost immediately, jumps to the ground and pupates in the soil ; the adult emerges about nine days later.

An attacked aphid assumes a characteristic spotty appearance about 36 hours before the parasite larva leaves it, hence the specific name of the latter, " *maculans*." The proportion of alates parasitised is much smaller than that of apteræ ; this is probably due to the parasite larva inhibiting wing development. This Cecidomyid has been found in almost every locality where it has been looked for, and though small colonies of aphids frequently escape parasitism altogether, in larger ones 50% or more, occasionally nearly 100%, are often attacked.

During the rainy season *T. aurantii* is also liable to be heavily attacked by entomogenous fungi.

The natural enemies of this aphid, in conjunction with the short time during which flush leaves are suitable as food, are nearly always capable of controlling it at a level of population at which no appreciable damage is done. Even when on rare occasions this is not so, it is unlikely that the use of insecticides would be desirable, for on heavily attacked trees the damage has already been done, but the aphid population has by then declined. Insecticides would kill the natural enemies which would otherwise be available for suppressing small outbreaks on neighbouring trees.

Aphis craccivora Koch (leguminosae Theobald)

This is the only other aphid that has been found on cacao in Trinidad. Cacao does not appear to be a normal host plant, but flourishing colonies sometimes develop on it when grown under the shade of *Gliricidia sepium*, a tree that is often severely damaged by *A. craccivora*. It has not, however, been seen in sufficient numbers to cause appreciable injury to the cacao.

Description

Wingless viviparous female : Length 1.7—2.0 mm., shining black, but fresh specimens with a slate-grey pruinosity that is readily lost. Cornicles 0.4 mm. long, slender, the basal third slightly swollen ; cauda half as long as cornicles. Antennæ with the two short basal joints dark, third, fourth and fifth white except at the extreme apices, sixth black. Legs mainly whitish, apices of fore and mid femora slightly, and of hind femora and all tibiæ more distinctly, brown ; tarsi brown.

Winged viviparous female : Length about 1.7 mm., cornicles 0.28 mm., cauda 0.14 mm. Third antennal joint with five or six circular sense organs in a single row. Forewings about 2.4 mm. long, media with two forks, stigma pale brown.

Life History

Very similar to that of *T. aurantii*, except that the number of alates produced is considerably less : it is uncommon to find a colony with more than 10% of winged forms. Mixed colonies of the two species are frequently met with.

Natural Enemies

The same predators that attack *T. aurantii* also attack this species. It is not a normal host of the endoparasitic Cecidomyid, *Pseudendaphis maculans*, but on one occasion a mixed colony of *T. aurantii* and *A. craccivora* was found, in which several of the former species and two apteræ of the latter were parasitised.

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Manurial and Cultural Experiments on Cacao. Part IV.

The Effects of Fertilisers, Shade and Spacing on Flowering, Fruit-set and Cherelle wilt. River Estate, Trinidad.

by

G. Havord, G. K. Maliphant and F. W. Cope.

THE manurial and cultural field experiments at River Estate have been described previously (Havord, 1953a, 1953b), and the first results of two of them have been presented (Havord, Maliphant and Cope, 1954). The present paper deals with further results obtained in the shade, spacing and fertiliser experiment (No. I) during the crop year September, 1953, to August, 1954.

As previously described in detail, the factors involved are permanent shade *versus* none, wide (12 × 12 feet) and close (8 × 8 feet) spacing, and the fertilisers ammonium sulphate, superphosphate and potassium sulphate factorially at two levels. An important change in the levels of fertilisers applied has been made. Applications had hitherto been at the rate of ¼ lb. of each fertiliser per tree soon after planting in 1949, and ½ lb. per tree annually in May thereafter. Since May, 1953, fertilisers have been applied at the rate of approximately 450 lb. of ammonium sulphate and 300 lb. each of superphosphate and potassium sulphate per acre, irrespective of spacing. (This corresponds to an application of 1½ lb. and 1 lb. respectively per tree at the wide spacing, and ⅝ lb. and ⅜ lb. per tree at the close spacing). It was considered more reasonable to apply fertilisers on an acreage basis from this stage since the tree canopy had nearly met and the root systems were by then effectively exploring the whole area of each plot. Separation trenches were dug annually between plots from 1953 onwards to prevent the spread of roots between plots. Starting in September, 1954, the guard plots are being utilised to study the effects of varying the rates and times of fertiliser applications.

Yield Results

During the crop year 1953-54, the mean yield of the experiment was 409 lb. of dry cacao per acre (Table I). There was a significant positive yield response to nitrogen fertiliser ($P<.05$) tending to be more pronounced in the absence of shade and at the wide spacing (interactions not quite significant). In fact, nitrogen fertilisers actually slightly depressed yields in shaded close-spaced plots. Phosphate fertilisers gave a slightly increased yield, but the effect fell far short of significance. The nitrogen × phosphate interaction (large, negative) indicates that plots receiving both nitrogen and phosphate fertilisers yielded no better than those receiving only one of them. Potassium fertiliser had no overall effect on yield, but tended to increase yields under shade and depress yields in its absence. The effect, noted in the first crop (*loc. cit.*), of potassium in depressing the phosphate response, was much less marked. The overall effect of permanent shade was to increase yields, but as the effect is confounded it is subject to large errors and failed to attain significance. The indications of the data are that the interactions of shade with fertilisers and spacing were of more importance than the direct effect. The temporary banana shade was progressively removed during the crop year, so that the

TABLE I

Yields in pounds of dry cacao per acre for combinations of shade, spacing and fertilisers.

		0	N	P	NP	K	NK	PK	NPK	Means
Close spacing	No shade ...	599	389	294	604	155	609	437	278	421
	Shade ...	351	539	727	477	607	505	537	519	533
	Means ...	475	464	521	541	381	557	487	399	477
Wide spacing ...	No shade ...	23	659	536	257	121	304	247	639	348
	Shade ...	202	274	297	442	293	481	293	380	333
	Means ...	113	467	417	350	207	393	270	510	341
Means		294	466	469	446	294	475	379	455	409

S.E. of difference of spacing means = ±41.2
S.E. of difference of fertilisers means = ±82.4
S.E. of difference, same row or column, body of table = ±164.7
} d.f. error 28

full effects of the shade treatment were only just beginning to be exerted.

Close-spaced trees highly significantly outyielded wide-spaced trees in weight of cacao per acre, but an analysis of numbers of pods per tree showed that close-spaced trees yielded highly significantly less per tree than wide-spaced trees. Girth measurements made in February, 1954, in general reflected the yield results.

The weight of wet cacao per pod for the various treatments showed a similar trend to previous results (*loc. cit.*) in that higher yield was associated with less cacao per pod. Over the whole experiment, the weight of wet cacao per pod was less in the 1953-54 crop than in the 1952-53 crop (133 grams and 146 grams respectively), again reflecting the association of less cacao per pod with higher yields.

In an attempt to elucidate the way in which those factors influencing crop production exerted their effects, a study of flowering intensity, cherelle set, cherelle wilt and final pod production on a sample of four trees at the centre of each plot was commenced in November, 1953. Owing to the difficulties of accurate recording in the dense foliage in the upper parts of the tree, data were recorded only between ground level and a painted band as close as practicable to the foliar crown. (Most of the crop is, in fact, borne on these portions of the tree.) Counts were made at fortnightly intervals of (i) the number of open flowers, (ii) the number of small cherelles, each being tagged with a small wire loop, (iii) the number of tagged cherelles wilted, (iv) the number of tagged pods lost through disease, and (v) the number of mature pods reaped.

Fig. 1 shows the crop reaped monthly in grams wet cacao per tree for shade and spacing combinations, averaged over fertiliser treatments. It can be seen that under shade the main crop was spread over a slightly longer period, but the reverse is true for the minor December to February crop. Similar graphs for individual fertiliser treatments show no effect of fertilisers on periodicity of cropping. Regardless of treatment, the bulk of the crop was reaped from May to July, 1954. It was thus possible to follow the development of this crop from the flowering stage, which preceded reaping by about 5½ months, through fruit setting and subsequent partial loss through wilt, on up to harvesting. Very few of the pods reaped were

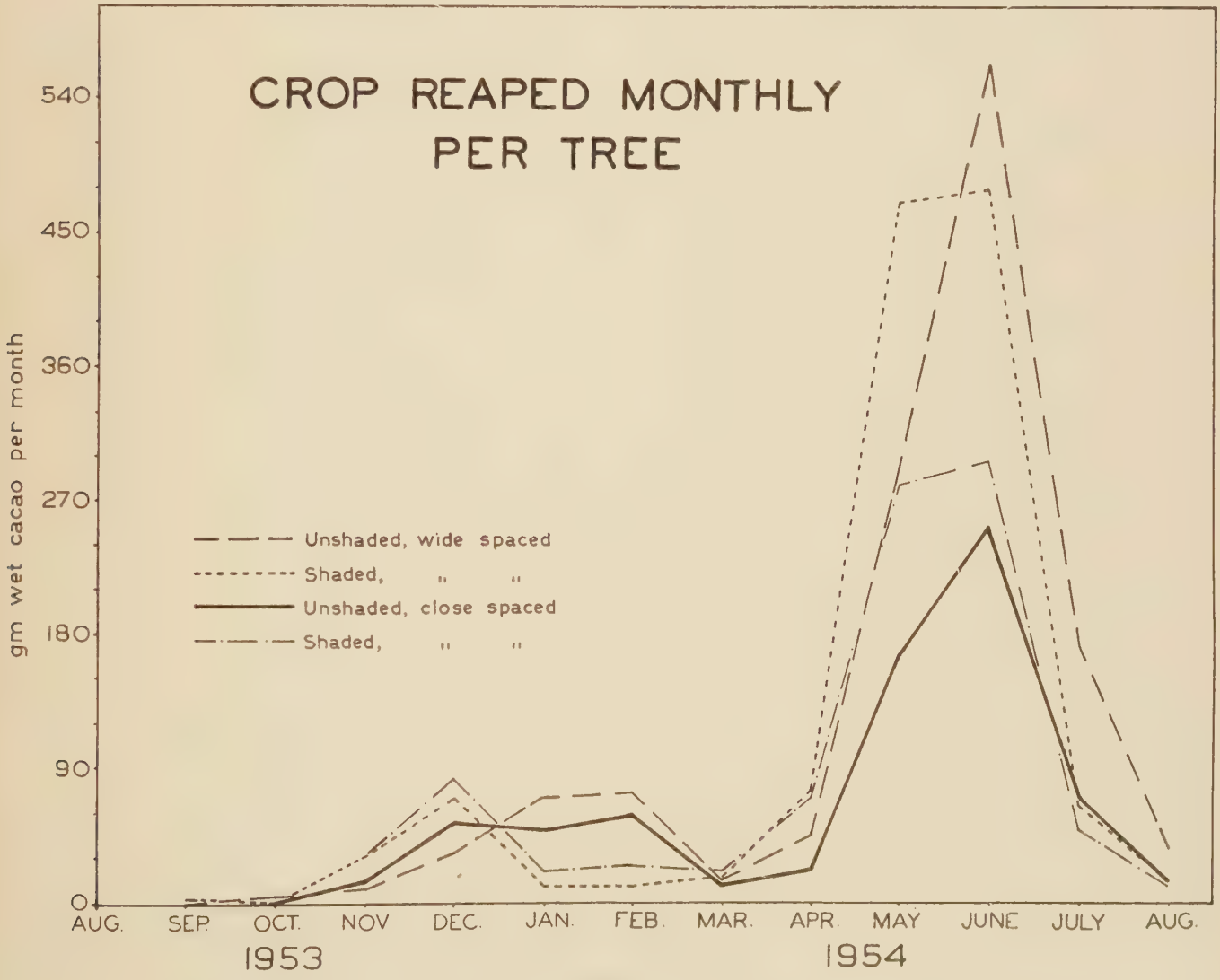

FIGURE 1

diseased, so that continuing investigation of this point, discussed in the last Report (*loc. cit.*) awaits further years' data.

Table II gives the magnitudes of the statistical treatment effects on flowering, cherelle set, cherelles set expressed as a percentage of flowers counted, percentage of set fruits wilted, and final crop, relative to the magnitude of an effect significant at the 5% level as 100, for recorded portions of the four sample trees in each plot. The final column shows, for comparison, the relative magnitudes of the effects on pod production from May to August *per tree* over the whole experiment. The effects in the last two columns are substantially similar, although statistical significance is attained more frequently and often at higher levels of probability owing to the larger sample. The correlation coefficient between total number of pods per plot and pods reaped from the recorded portions of the sample trees was +0.657 ($P<0.1\%$). Thus the pods counted from the sample trees are an adequate measure of the whole-plot performance.

TABLE II

Relative magnitude of main effects and interactions on flowering, setting, wilting and final crop, expressed as percentages of the least significant differences at the 5% level.

S = shade—no shade (main effect confounded with block differences).
C = close spacing—wide spacing.
N = nitrogen manured—unmanured, etc.

Effect symbol	Flowering	Cherelles set (actual counts)	Cherelles set (as transformed % flowers counted)	% wilt (transformed)	Final crop based on 4 sample trees	Final crop (per tree, based on whole plot)
S (conf'd) ...	+	+	+	—	+	+
C	—96	—106*	9	145**	—205***	—301***
SC	30	13	—15	80	—8	—43
N	60	74	—23	—2	77	143***
SN	—65	—47	27	—15	—10	—102*
CN	—28	—40	—24	182***	—123*	—164**
SCN	—17	—12	9	—37	—5	43
P	78	43	—15	—52	49	87
SP	—17	—70	—142**	—9	—48	—24
CP	—12	—24	—65	78	—77	—89
SCP	78	131*	38	47	83	64
NP	—48	—77	—78	—22	—55	—118*
SNP	20	30	43	—45	51	69
CNP	78	66	67	—99	93	74
SCNP ...	—66	—71	—50	59	—115*	—96
K	26	22	30	62	2	—11
SK	40	44	—70	—128*	85	54
CK	—12	—30	—44	5	—52	—5
SCK	—1	—8	25	30	—13	—41
NK	—5	—3	7	—89	20	57
SNK	23	9	68	110*	—48	—33
CNK ...	10	4	54	—23	25	—20
SCNK ...	4	83	37	—82	76	7
PK	19	11	24	—59	11	—8
SPK	—100*	—57	16	65	—81	—102*
CPK	—31	—18	3	24	13	4
SCPK ...	49	—17	—12	—8	—12	63
NPK	74	84	—19	114*	36	87
SNPK ...	—5	16	—4	—3	—1	—68
CNPK (conf'd)	—	—	+	—	—	—
SCNPK (conf'd)	—	+	—	—	+	+

* significance at $P=5\%$.
** " $P=1\%$.
*** " $P=0.1\%$.

Shade

Although the overall effect of shade was to increase flowering and cherelle set and to decrease wilt, thus increasing the final crop, these effects lack significance, since the contrast is confounded with block differences. It is noteworthy that the combination of the shade factor with any other factor or set of factors usually reverses the sign of the statistical effect, indicating that most responses are more marked in the absence of shade (Table II).

Spacing

Wide-spaced trees very highly significantly outyielded close-spaced trees, traceable to enhanced flowering and a consequent increase in cherelle set, and also to much reduced wilt, the latter especially in the absence of shade (Tables II and III).

Nitrogen Fertiliser

The response to nitrogen fertiliser in number of pods produced was largely due to enhanced flowering, and the consequent increased set of cherelles. The percentage of flowers setting fruit was little affected. However, at the close spacing, the already high incidence of wilt was further increased by nitrogen fertiliser whereas, at the wide spacing, nitrogen fertiliser markedly reduced wilt

(large positive CN interaction for wilt, P<.001) (Tables II and III).

Phosphate Fertiliser

This exerted a small beneficial effect throughout the fruiting cycle. The effect on flowering only occurred on the close-spaced unshaded and wide-spaced shaded plots, and that on wilt on the wide-spaced plots. In addition, phosphate fertiliser appears to have increased the proportion of flowers setting cherelles in the absence of shade at the wide-spacing, and to have reduced this proportion under shade. The final effect of these complicated interactions on yield was that without shade only wide-spaced fertilised trees gave high yields, whereas in the presence of shade wide-spacing gave most yield, phosphate having little effect (Tables II and IV).

*Table III

The effects of nitrogen fertiliser and spacing on flowering intensity, set of cherelles, wilt, and pod yield. (Totals for four trees.)

	Flower Count			Cherelles set (actual count)			Cherelles set as % of Flowers counted			Percentage wilt (actual)			Pods harvested		
	—N	+N	Mean	—N	+N	Mean	—N	+N	Mean	—N	+N	Mean	—N	+N	Mean
Close spacing ...	208.81	236.63	**222.72**	67.8	75.8	**71.8**	32.5	32.0	**32.2**	77.3	82.8	**80.2**	15.4	13.0	**14.2**
Wide spacing ...	268.31	345.63	**306.97**	83.3	110.3	**96.8**	31.0	31.9	**31.5**	76.4	72.6	**74.3**	19.7	30.2	**24.9**
Mean	**238.56**	**291.13**		**75.6**	**93.0**		**31.7**	**31.9**		**76.9**	**76.8**		**17.5**	**21.6**	

* In Tables III-VI, Means in heavy type were derived directly from the original data, and are not necessarily exact means of the appropriate figures in the body of the tables.

Table IV

The effects of phosphate fertiliser, shade and spacing on flowering intensity, set of cherelles, wilt and pod yield. (Totals for four trees.)

	Flower Count			Cherelles set (actual count)			Cherelles set as % of Flowers counted			Percentage wilt (actual)			Pods harvested		
	—P	+P	Means	—P	+P	Means	—P	+P	Means	—P	+P	Means	—P	+P	Means
Close spacing unshaded ...	206.63	211.25	**208.94**	68.5	58.4	**63.4**	33.2	27.6	**30.3**	79.9	82.2	**80.9**	13.8	10.4	**12.1**
shaded	181.13	291.88	**236.50**	70.8	89.6	**80.2**	39.1	30.7	**33.9**	77.3	81.6	**79.7**	16.1	16.5	**16.3**
Means	**193.88**	**251.56**	**222.72**	**69.6**	**74.0**	**71.8**	**35.9**	**29.4**	**32.2**	**78.6**	**81.9**	**80.2**	**14.9**	**13.4**	**14.2**
Wide spacing unshaded ...	238.13	400.00	**319.06**	59.9	123.1	**91.5**	25.2	30.8	**28.7**	74.0	76.4	**75.5**	15.6	29.1	**22.4**
shaded	297.25	292.50	**294.88**	117.9	86.3	**102.1**	39.7	29.5	**34.6**	76.6	68.3	**73.1**	27.6	27.4	**27.5**
Means	**267.69**	**346.25**	**306.97**	**88.9**	**104.7**	**96.8**	**33.2**	**30.2**	**31.5**	**75.7**	**73.0**	**74.3**	**21.6**	**28.3**	**24.9**
Means	**230.78**	**298.91**		**79.3**	**89.4**		**34.4**	**29.9**		**76.9**	**76.7**		**18.3**	**20.8**	

Potassium Fertiliser

In unshaded plots, potassium fertiliser in the absence of nitrogen markedly increased wilt, but not in the presence of nitrogen fertiliser, whereas in shaded plots potassium fertiliser reduced cherelle wilt (P<.05 for the interaction). In addition, potassium fertiliser tended (non-significantly) to reduce flowering and cherelle set in unshaded plots and the reverse in shaded plots. This resulted in a positive crop response to potassium fertiliser in shaded plots and a depression in yield from unshaded plots (the interaction is large and positive, but fails to attain significance). The presence of phosphate fertiliser reversed the tendency for potash to reduce flowering and consequent cherelle set in unshaded conditions, and nullified this effect in the presence of shade (P=.05 for the interaction) (Tables II, V and VI).

The large NPK interactions in Table II are difficult to interpret, since they involve averaging the contrasts between shade and spacings which have been shown to have profound effects. However, the highest yield per tree was obtained when all three fertilisers were applied. This is traceable largely to enhancement of the beneficial effect of nitrogen on flowering by the addition of phosphate and potassium fertilisers, the ameliorating effect of nitrogen on increased cherelle wilt due to potassium, and to the amelioration by phosphate of the reduction in flowering due to potassium.

TABLE V

The effects of potassium and nitrogen fertilisers and shade on flowering intensity, cherelle set, wilt and pod yield. (Totals for four trees.)

	Flower Count			Cherelles set (actual count)			Cherelles set as % of Flowers counted			Percentage wilt (actual)			Pods harvested		
	—K	+K	Mean	—K	+K	Mean	—K	+K	Mean	—K	+K	Mean	—K	+K	Mean
Unshaded —N ...	202.75	215.50	**209.13**	64.4	62.0	**63.2**	31.8	28.8	**30.2**	70.7	82.3	**76.4**	18.9	11.0	**14.9**
+N ...	337.25	300.50	**318.88**	95.8	87.8	**91.8**	28.4	29.2	**28.8**	79.2	78.2	**78.8**	19.9	19.1	**19.5**
Means	**270.00**	**258.00**	**264.00**	**80.1**	**74.9**	**77.5**	**29.7**	**29.0**	**29.4**	**75.8**	**79.8**	**77.8**	**19.4**	**15.1**	**17.2**
Shaded —N ...	247.50	288.50	**268.00**	81.0	94.9	**87.9**	32.7	32.9	**32.8**	78.9	75.7	**77.1**	17.1	23.1	**20.1**
+N ...	226.50	300.25	**263.38**	85.8	102.9	**94.3**	37.9	34.3	**35.8**	74.2	75.4	**74.9**	22.1	25.3	**23.7**
Means	**237.00**	**294.38**	**265.69**	**83.4**	**98.9**	**91.1**	**35.2**	**33.6**	**34.3**	**76.5**	**75.5**	**76.0**	**19.6**	**24.2**	**21.9**
Means	**253.50**	**276.19**		**81.7**	**86.9**		**32.2**	**31.5**		**76.1**	**77.4**		**19.5**	**19.6**	

TABLE VI

The effects of potassium and phosphate fertiliser and shade on flowering intensity, cherelle set, wilt and pod yield. (Totals for four trees.)

	Flower Count			Cherelles set (actual count)			Cherelles set as % of Flowers counted			Percentage wilt (actual)			Pods harvested		
	—K	+K	Mean	—K	+K	Mean	—K	+K	Mean	—K	+K	Mean	—K	+K	Mean
Unshaded —P ...	280.75	164.00	**222.38**	74.9	53.5	**64.2**	26.7	32.6	**28.9**	74.2	81.1	**77.1**	19.3	10.1	**14.7**
+P ...	259.25	352.00	**305.63**	85.3	96.3	**90.8**	32.9	27.4	**29.7**	77.1	79.2	**78.2**	19.5	20.0	**19.8**
Means	**270.00**	**258.00**	**264.00**	**80.1**	**74.9**	**77.5**	**29.7**	**29.0**	**29.4**	**75.8**	**79.8**	**77.8**	**19.4**	**15.1**	**17.2**
Shaded —P ...	175.00	303.38	**239.19**	81.1	107.5	**94.3**	46.3	35.4	**39.4**	78.1	75.8	**76.8**	17.8	26.0	**21.9**
+P ...	299.00	285.38	**292.19**	85.6	90.3	**87.9**	28.6	31.6	**30.1**	74.9	75.2	**75.1**	21.5	22.4	**21.9**
Means	**237.00**	**294.38**	**265.69**	**83.4**	**98.9**	**91.1**	**35.2**	**33.6**	**34.3**	**76.5**	**75.5**	**76.0**	**19.6**	**24.2**	**21.9**
Means	**253.50**	**276.19**		**81.7**	**86.9**		**32.2**	**31.5**		**76.1**	**77.4**		**19.5**	**19.6**	

Throughout the data, cherelle set follows closely the trend of flowering intensity. The regression coefficient of cherelle set on flowering intensity is highly significant, and an analysis of cherelles set as percentages of flowers counted (transformed to angles) gives only one significant effect, the shade × phosphate interaction, as discussed above. Thus, in general, pollination efficiency must be fairly uniform over all treatments.

Discussion

It has usually been considered that the main factors limiting the yielding capacity of the cacao tree are that flowers remain a relatively short time on the tree and that cherelle wilt at a very early age is responsible for the loss of a very high proportion (ranging from 20% to 90%) of the fruit which is set. Flowering and the efficiency of pollination (except in the case of large blocks of self incompatible trees) have not usually been considered limiting factors. Pound (1932) and McDonald (1932) studied fruit set, and observed increased flower abscission during dry spells, and Pound (1932) advanced the hypothesis that nitrogen nutrition plays an important part in fruit set. Pound and De Verteuil (1935) reported that phosphate fertiliser increased fruit set, and potash fertiliser also tended to increase fruit set, but this effect was reduced by the addition of nitrogen. They also observed that potassium and phosphate fertilisers tended to increase wilt, and that nitrogen fertiliser to some extent allayed the effect of potassium fertiliser.

Pound (1936) later observed that fertilisers did not affect the time at which flowering, fruit-set and leaf-flushing occurred, and that flowering and setting were increased by nitrogen, phosphate, and potassium fertilisers but increased cherelle wilt also resulted. Only in the case of potash was the balance between these effects sufficient to give a yield increase. Cope (1939, 1940) found that phosphate and especially potassium fertilisers increased flowering, but not the proportion of flowers which set fruit, and that potassium fertiliser decreased cherelle wilt, but that phosphate had little effect.

Against the background of these sometimes conflicting results, Humphries began his intensive investigations of

the subject in 1939. (Humphries 1941, 1943, 1944, 1947, 1950.) His main conclusions were that cherelle wilt is caused by competition within the plant for water and mineral nutrients, particularly potassium, but not for carbohydrates, and that this is accentuated when a crop is maturing and when a new leaf flush is developing. This theory was supported in the main by chemical analyses of various parts of the tree and tested by removing the developing crop from certain trees and noting a reduction in the incidence of wilt. Humphries did not, however, report the effect of supplying additional nutrients.

Evans and Murray (1953) working with very young cacao, found much reduced flowering and fruiting at high light intensities, and that nitrogen and phosphate fertilisers increased flowering at high light intensities, but these results were not subjected to statistical analysis. Murray (1954) noted that cherelles were set over a considerable period of time under shaded conditions, but " appeared with a rush " at high light intensities. Also, he adduces some evidence that cherelle wilt is reduced by fertiliser applications, but in this instance recorded only cherelles over 5 cm. in length and compared only NPK fertiliser *versus* none. He notes that his data are incomplete as they do not take account of differences in fruit set, nor of cherelles wilting whilst less than 5 cm. long. Murray (1953) reported that injections of a complete nutrient solution and of potassium sulphate solutions failed to reduce cherelle wilt or to increase yield.

In discussing the present work in relation to past results, it should be borne in mind that apart from the work of Evans and Murray most of the previous data were also recorded from River Estate, but from mature seedling trees of varying ages spaced 12 feet apart and under Immortelle shade.

Although wide-spaced trees yielded far more cacao per tree than close-spaced trees, due to increased flowering and a consequent better set of cherelles and a reduction of cherelle wilt, this increase was not sufficient to compensate for the smaller number of trees per acre at the wide spacing (302 trees per acre at the wide spacing, and 681 at the close spacing), so that much more cacao per acre was reaped from the close-planted trees. During the first crop year (Havord, *et al.*, *loc. cit.*) there was little difference in the crop per tree, so that, on an acreage basis, close-spaced plots far outyielded wide-spaced plots. It will be important to see whether the yield per acre of wide-spaced trees eventually equals or exceeds that of close-spaced trees, as was the case in an early experiment at River Estate (Freeman, 1929). It is noteworthy that, by the end of the 1953-54 crop season, ground vegetation had been almost completely suppressed under the close-spaced trees, but was still abundant at the wide spacing, especially in the absence of shade.

The lack of response to nitrogen fertiliser under the densest shade conditions (shaded, close-spaced plots) in the present experiment is in accord with results reported by Murray elsewhere in this Report. The reduced response due to close-spacing in unshaded conditions and the recent work of Murray indicate that with young cacao this is mainly an effect of light intensity, rather than utilisation of nitrogen by or provision of nitrogen by the leguminous shade trees, as suggested for mature cacao by McDonald (1936) and Hardy (1937, 1938, 1939). Further evidence on this point should be forthcoming from the leguminous *versus* non-leguminous shade tree experiment (Expt. II).

The effect of nitrogen fertilisers in enhancing flowering and consequent fruit set, but with little effect on the proportion of flowers setting fruit, is in accord with Pound's conclusion, but it should be remembered that our data did not distinguish between intensity of flowering and premature abscission of flowers since the flower counts were carried out at fortnightly intervals and so did not take account of every flower produced. Pound observed that nitrogen fertiliser increased wilt, whereas in our data this was true at the close-spacing, but did not occur at the wide-spacing.

The general beneficial effect of phosphate fertiliser on all stages of the fruiting cycle, especially at the wide spacing and in the absence of shade, is not fully in accord with previous data.

The findings of Pound that potassium increased cherelle wilt were contradicted by the investigations of Cope and Humphries. The present work has revealed that under shaded conditions, potassium fertilisers did decrease wilt, as reported by Cope and to be expected from the work of Humphries, but under unshaded conditions the reverse was true. Yet the amelioration of the latter effect by the addition of nitrogen fertiliser is in accord with the results of Pound.

Possibly these apparent contradictions are partly explicable by differences in degree of shade and the age of the trees. The present data emphasise the importance of the interactions between shade and nutrition, and indicate that the effects of fertilisers upon flowering, cherelle set, and cherelle wilt are by no means simple. Different fertilisers may affect different stages of the fruiting cycle and the effect of one fertiliser may be profoundly influenced by the presence or absence of others ; and all the effects are much modified by the shade conditions and by the spacing of the trees which, of course, is itself partly a shade effect. The whole fruiting cycle thus appears to be very sensitive to physiological changes in the trees as determined by its mineral nutrition and the degree of shade.

Finally, it should be stated that these results cover only one cropping period with young cacao, and that further records may clarify or extend the conclusions. Work is in progress on chemical foliar analysis, and the responses of the trees to different soil moisture conditions, under the various treatments. The results of this work, in conjunction with further records of the type reported, may lead to a better understanding of the causes of the phenomena. Meanwhile, it is apparent that fundamental work on the effects of fertilisers on the cacao tree can only be carried out if shade conditions are carefully controlled, and preferably subjected to controlled experimental variation.

Summary

The results of a shade, spacing and fertiliser field experiment on cacao for the crop year 1953-54 are presented and discussed. Observations of flowering, fruit set and cherelle wilt provided data on the effect of the experimental treatments at different stages of the fruiting cycle. It was apparent that the effects of fertilisers at different stages of the fruiting cycle were complex, and often profoundly modified by the presence or absence of overhead shade, and by the spacing of the cacao trees.

Close-spaced trees outyielded wide-spaced trees in crop per acre, but were markedly inferior in single tree performance, flowering and cherelle wilt being adversely affected. There were positive yield responses to nitrogen

fertiliser, greatest in unshaded and wide-spaced plots, but there was a negative response in the shaded, close-spaced plots (i.e., those most heavily shaded). Nitrogen fertiliser enhanced flowering, and in addition, cherelle wilt was reduced in the wide-spaced plots, but increased in the close-spaced plots. Under certain conditions of shade and spacing, phosphate fertiliser exerted a small beneficial effect on all stages of the fruiting cycle. Potassium fertiliser reduced cherelle wilt in shaded plots, but increased wilt in unshaded plots. The latter effect was ameliorated by the presence of nitrogen fertiliser. Generally, increased yield was associated with decreased weight of wet cacao per pod.

Previous work on similar topics is reviewed, and the present results are discussed in relation thereto. It is suggested that the marked interaction between shade, spacing and fertiliser responses may, in part, explain discrepancies between past and present results.

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Manurial and Cultural Experiments on Cacao. Part V.

River Estate, Trinidad.

by

G. Havord, G. K. Maliphant and F. W. Cope

THE manurial and cultural field experiments at River Estate have been described previously (Havord, 1953a, 1953b), and the first results of two of them have been presented (Havord, Maliphant and Cope, 1954). This paper presents results from Experiments II, III and IV recorded in the crop year 1953-54.

Data recorded were (1) yield, in pounds of dry cacao per acre, per plot (recorded as weight of wet cacao per plot, and converted to dry weight by multiplication by the factor 0.40), and (2) girth at 3 inches above ground level, taken in February, 1954. When, at this level, there was more than one branch and/or chupon, a value based on the combined cross-sectional area of the branches was computed. Girth results were similar to yield results in all the experiments.

LEGUMINOUS AND NON-LEGUMINOUS SHADE EXPERIMENT (EXPT. II)

The factors involved in this experiment, planted in 1950, are (1) leguminous shade trees, Immortelle and *Peltophorum ferruginium*, *versus* non-leguminous shade trees, Pink Poui and *Theobroma bicolor*, and (2) NPK *versus* PK fertilisers. Fertilisers applied were ammonium sulphate, superphosphate and potassium chloride at rates of 150 lb. per acre each in May, 1951, 2 and 3, and 450, 300 and 300 lb. per acre respectively in 1954. Four clones, ICS 1, 8, 16 and 98 are planted.

Table I shows that there are wide significant differences between the performances of the clones. ICS 1 yielded extremely well, ICS 8 moderately well, but ICS 16 and 98 were very poor in comparison. Although there was a response to nitrogen fertiliser this failed to attain significance. There were no significant differences between shade treatments.

TABLE I

Mean yields, in lb. dry cacao per acre, for combinations of clones and fertilisers in Experiment II.

	ICS 1	ICS 8	ICS 16	ICS 98	Means
NPK	446	263	75	51	209
PK	434	218	58	30	185
Means ...	440	240	67	41	197

S.E. of difference of clone means ±29.8 (d.f.=72)
S.E. of difference of fertiliser means ±20.2 (d.f.=12)
S.E. of difference of clone means, same fertiliser ±42.1 (d.f.=72)
S.E. of difference of fertiliser means, same clone ±59.0 (d.f.=30 equivalent).

SPACING, MULCHING AND TRENCHING EXPERIMENT (EXPT. III)

The treatments in this experiment, planted in 1949, are (1) No mulch *versus* cut bush mulch *versus* bagasse mulch *versus* trenched mulch; (2) Close (7.2×7.2 ft.) *versus* wide (9×9 ft.) spacing; and (3) Four clones, ICS 1, 6, 8, 60. Permanent shade is not provided. The rates of application of mulch prior to 31st August, 1953, were given previously (*loc. cit.*). It was then apparent that, owing to the slower rate of decomposition of the bagasse mulch than the bush mulch, approximately equivalent quantities of major nutrients could only be applied by addition of some chemical fertilisers to the bagasse plots. Cut bush mulch was applied at a rate of 12 tons (fresh weight) per acre in November, 1953, and May, 1954; bagasse mulch was applied at 19 tons per acre in March, 1954, and the additional fertiliser in August, 1954. The trench mulching is due for renewal in 1955. The quantities of major nutrients supplied in the crop year 1953-54, in lb. per acre were :—

	As mulches			As chemical fertilisers		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Cut bush ...	175	46	212	0	0	0
Bagasse ...	58	26	34	114	20	170

Closer spaced plots yielded 461 lb. per acre and the wider spaced plots 457 lb. per acre. During the previous crop year (*loc. cit.*), close-spaced plots far outyielded wide-spaced plots on an acreage basis, but this effect had already disappeared by the second crop (*cf.* Expt. I, *loc. cit.*)

TABLE II

Mean yields in lb. dry cacao per acre, adjusted for confounding, for combinations of mulch treatments and clones in Experiment III.

	ICS 1	ICS 6	ICS 8	ICS 60	Means
Bagasse ...	408	185	558	215	342
Cut brush ...	697	155	698	259	452
Trenched ...	646	341	587	529	526
Control ...	617	407	691	351	517
Means ...	592	272	634	339	459

S.E. of difference of mulch or clone means ±63
S.E. of difference in body of table ±197 } (d.f. error 26)

Bagasse treated plots gave significantly less yield than trenched or control plots ($P<.01$) and nearly significantly less than cut bush plots; the differences between the latter three were small and non-significant (Table II). Clonal contrasts were marked. ICS 1 and ICS 8 significantly outyielded ICS 6 and ICS 60 ($P<.001$). ICS 1 and ICS 8 were also reasonably consistent in performance over the four treatments, but ICS 6 and ICS 60 gave widely different responses to them. ICS 6 receiving cut bush or bagasse performed extremely poorly, the yields being significantly lower than those from several other clone and treatment combinations. ICS 60, it should be noted, was planted one year later than the other three.

The most remarkable fact emerging from this experiment was the wide variation in results from duplicate plots, a variation further traced to differences between individual trees. This was such that in one plot adjacent trees yielded 26 and 0 pods respectively (and many similar examples could be quoted) despite the fact that their root systems are greatly interlaced. Attempts to relate the variability to soil factors by plotting yield data in various ways led to the conclusion that it cannot be ascribed to fertility trends, but is distributed randomly over the experimental area.

An attempt was made to discover the origin of this variation by studying flower set, cherelle set and wilt, and pods reaped, by records similar to those taken in Experiment I (*loc. cit.*). The clones were treated separately and the trees studied (3 per plot) divided into categories according to their pod productions during the whole cropping season, expressed as a percentage of the average pod production of that clone over the whole experiment. For this investigation the effects of treatments on tree yields were ignored. Whatever the cause of the tree-to-tree variation, it affected all stages of the fruiting cycle. High bearing trees flowered at a greater intensity, set more cherelles and lost less by wilt than poor bearing trees. These facts are illustrated in Table III, which is based on records taken between December, 1953, and August, 1954.

TABLE III

Flowering intensity, cherelle set, cherelle wilt and pod yield for three "yield categories."

	Flowers/tree			Cherelle set as percentage of flowers counted			Percentages cherelles wilted			Pods reaped per tree		
Yield group	High	Moder-ate	Poor	High	Moder-ate	Poor	High	Moder-ate	Poor	High	Moder-ate	Poor
Clone												
ICS 1	77	86	46	49	33	31	75	78	86	9.0	5.5	1.8
ICS 6	34	23	10	28	26	25	62	50	86	3.7	3.0	0.3
ICS 8	48	47	34	53	50	39	80	83	84	5.0	4.0	2.0
ICS 60 ...	91	87	38	15	15	11	55	74	88	6.6	3.6	0.5

Soil samples were collected from the top 1 inch of each of the surface mulched and unmulched plots, after carefully removing all traces of undecomposed and partly decomposed mulch, in February, 1954, nearly three years after the mulch applications began. Crumb stability was measured by a modification of the method of Smith and Cernuda (1951), calculating a "crumb stability index" by dividing the original weight (air-dry) of an aggregate into its weight after subjecting to the impact of 60 water drops each of 0.1 ml. falling from a height of 60 cm. at one drop per second. It was demonstrated that the crumb stability, percentage pore-space, and content of organic matter in the top inch of soil were increased by both mulches, and particularly by the bagasse mulch. The total nitrogen content was also increased, but equally by both mulches, so that the carbon : nitrogen ratio was higher under the bagasse mulch, but little affected by the bush mulch. These results are summarised in Table IV.

TABLE IV

Effect of mulches on soil conditions in the top inch layer of soil (Means of 16 determinations for each mulch).

	Bagasse mulch	Bush mulch	Control	Least significant differences
Stability index	0.634	0.629	0.476	0.128 for P= .01
Total pore-space (volume %)	70.2	65.4	61.1	3.5 for P =.05 4.7 for P =.01
Organic matter (%)	9.57	7.13	5.57	1.32 for P =.05 1.76 for P =.01
Total nitrogen (%)	0.353	0.352	0.272	0.063 for P =.01
Carbon : nitrogen ratio	15.84	11.77	11.86	2.14 for P =.01

It was not possible to demonstrate significant changes in potassium or phosphate status, although statistically non-significant trends towards increased status were apparent on the bush mulched plots.

TILLAGE AND MANURIAL EXPERIMENT (EXPT. IV)

The factors involved in this experiment, planted in 1950, are (1) land untouched *versus* hand forking *versus* shallow mechanical ploughing and (2) control *versus* chemical fertiliser *versus* pen manure fortified with chemical fertilisers *versus* grass mulch fortified with chemical fertilisers. Two clones, ICS 1 and 45, are used and Immortelle shade is planted throughout.

It was originally intended to maintain the applications of major nutrients, carried out in April-May annually, in the various treatments at levels per tree approximating to those in Experiment I (*q.v., loc. cit.*), but it was found that larger quantities than this were supplied by the bush mulch if an adequate cover was to be maintained. From 1st September, 1953, therefore, the manuring programme has been amended on an acreage basis. Pen manure was applied at a rate of 6.5 tons per acre in May, 1954, immediately prior to soil cultivation, so that it was incorporated in the soil in the cultivation treatments. Bush mulch was applied at a rate of 12 tons per acre in November, 1953, and in May, 1954, immediately after soil cultivation. The quantities of major nutrients applied up till the end of the 1953-54 crop year, in lb. per acre, were :—

	1/9/50 to 1/9/53			From 1/9/53 to 31/8/54					
				As organic manure			As chemical fertiliser		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
NPK plots	60	60	150	—	—	—	172	59	122
Pen manure plots... ...	108	63	156	62	32	82	110	27	38
Bush mulched plots ...	327	102	549	171	59	121	0	0	0

The yield results, given in Table V, showed ICS 45 to be greatly inferior to ICS 1. The statistical analysis of the data was, therefore, carried out for the clones separately. With ICS 1, the mean of all uncultivated plots was significantly greater than the means of both cultivated and hand-formed plots. This was because bush mulch only gave a significant increase in yield over the other three manurial treatments on uncultivated plots ($P<.01$ for the interaction). Although there were no significant effects with ICS 45, responses followed the same trends as with ICS 1.

TABLE V

Mean yields, in lb. dry cacao per acre, in Experiment IV.

	ICS 1				ICS 45			
	No cultivation	Mechanical cultivation	Hand forking	Means	No cultivation	Mechanical cultivation	Hand forking	Means
Control ...	261	262	150	225	47	16	27	30
Pen manure ...	263	110	229	201	29	60	12	34
NPK	177	192	54	141	56	28	20	52
Bush mulch ...	485	114	134	244	79	42	34	52
	297	170	142	203	53	37	23	37

S.E. for cultivation means (ICS 1 only) $\pm$44 (d.f. error 6).
S.E. for manuring means (ICS 1 only) $\pm$36 (d.f. error 27).
S.E. for manuring means in same cultivation (ICS 1 only) $\pm$77 (d.f. error 27).
S.E. for cultivation means in same manuring (ICS 1 only) $\pm$76 (equivalent d.f. error 14).

Summary of Main Conclusions and Discussion

The outstanding feature of the early results in the three experiments described is the difference in performance of the various clones. The precocity and tendency towards uniformity of performance of ICS 1 is apparent, and ICS 8 has also given good early yield. ICS 6, on the other hand, gave only moderate yields in Experiment III when averaged over the four treatments ; the yield from the control plots, however, was reasonably good and compares favourably with the yields obtained from ICS 6 in the clonal trials (CRB experiments), established nearby, at similar age. ICS 16 and ICS 45 (a criollo clone) both gave poor early yield ; these clones performed rather more efficiently in the CRB experiments at the same age, being but little inferior to ICS 1. ICS 98, in Experiment II, has given extremely low yields, which is in marked contrast to its CRB experiment performance where, in its early years, it was only somewhat inferior to ICS 1. ICS 60, like ICS 6, appears to be markedly affected by experimental treatment (Experiment II).

The absence of any differential effect of leguminous or non-leguminous shade trees in the early crop is not unexpected, since the shade trees are yet rather young to exert any effects. The increase in yield due to nitrogen fertiliser in Experiment II, though non-significant, agrees with the earlier results from Experiment I (*loc. cit.*), but the lack of response to mixed NPK fertilisers and to pen

manure in Experiment IV is surprising. There was a marked response to cut bush mulching on the uncultivated plots, but the lack of response to mulches in Experiment III and, indeed, the depression of yield by bagasse mulch, are contrary to expectations and require careful study in subsequent years. This occurred despite the demonstrated improvement in surface soil conditions, where the bulk of the roots are situated.

The disappointing yields of some clones, and the influence which experimental treatments have on performance, sound a warning against the facile assumption that clonal cacao will perform equally well from site to site. The remarkable tree-to-tree variation noted in the Experiment III shows that the purely local conditions at each tree planting site may profoundly modify a tree's performance. It has not yet been possible to establish the cause of the variability, but work continues on this point. Unless the factor or factors responsible for impairing performance under such strictly local conditions can be identified, and remedial measures devised, it becomes a matter of deep concern that for many clones it is impossible to predict performance, even from field to adjacent field.

Summary

Results from three field experiments on young cacao are presented. The main feature was the wide differences in the performance of different clones under varying conditions, and the implications of this are discussed.

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A Note on Soil Heterogeneity and the Growth of Cacao

by

G. Havord

It has long been known that very wide variability in performance from tree to tree is a pronounced feature in Trinidad cacao. This has in the past been attributed largely to genetical heterogeneity among the seedling population, and Jolly (1953) recently showed that the variability from tree to tree between seedlings is greater than between cuttings. However, Shephard (1937) established the important effect of soil type on the number of non-bearing or unprofitable trees. Pound (1937) took certain precautions to avoid the effects of soil heterogeneity in making the Imperial College selections, but evidence is now accumulating that equally wide variations can occur among clonal trees, as discussed elsewhere in this report by Fennah and by Havord, Maliphant and Cope. It may be, therefore, that very localised soil variations are responsible. Hardy (1943) pointed out the existence of wide differences in soil aeration from tree site to tree site. He wrote : " The demonstration . . . of such marked differences between the soil environments of small contiguous areas or tree-sites reveals the true reality of soil heterogeneity. Environmental variations are, indeed, likely to be common in the cacao fields of Trinidad, especially where the soil type is alluvial or detrital ; the evidence may adequately explain marked differences in growth and yield of individual trees or groups of trees that are frequently observed by planters and employed by botanists when selecting high bearing strains of cacao trees." The recognition of the importance of soil variability to the planter is the reason for the minutely detailed soil survey now in progress in the Central Range of Trinidad (one of the most important cacao producing areas), mentioned in the Introduction to last year's Report on cacao research (p. 7).

In this connection, work carried out in 1951 in Experiment I at River Estate becomes of wider interest. A report of the work was circulated internally at the time, but was not published, and is summarised below.

It was noted in July, 1951, when the experiment had been planted just two years, that the growth of cacao was very uneven, and was particularly poor in six plots in the N.E. section of the area. Trees here were very small and stunted, with small chlorotic leaves and often showed severe " die-back." Many trees were only 12 and 18 inches high, compared with 4 to 5 feet in surrounding plots ; several seemed unlikely to survive. The trees gave every appearance of suffering from soil waterlogging and gave marked responses to diagnostic foliar injections of nitrogen (carried out by Dr. H. Evans). Several other areas also showed poor growth, but were less badly affected and less well defined. Although the worst " bad area " included two " control " plots (no fertiliser), other control plots nearby appeared to be perfectly healthy. The bad areas were accurately mapped by individual assessments of the vigour of each of the 5,504 trees in the experiment and the resulting data used to plot a plan showing tree vigour in colours (not reproduced). The two worst areas carried approximately 70 and 50 " bad " trees respectively, but many of these were adjacent to perfectly healthy trees. The plan also showed up the general prevalence of relatively poor trees in the N.E. portion of the field.

Two soil pits were prepared, No. 1 inside the most marked " bad area," and No. 2 in an adjacent area of good cacao, and were sampled for laboratory examination. Composite auger samples from the top 6 inches and second 6 inches were also taken from inside each of the three worst " bad areas " and from the " good " cacao around them. The results of these analyses are given in Tables I and II.

The chemical data show only small differences between good and bad areas. Nutrient status is generally low, and P and K status particularly low. The only tendency noted is that the organic matter, N, C/N ratio and P_2O_5 values are all slightly higher for areas 1 and 2 in the good cacao than in the bad. The differences are small, however, and the position is reversed in area 3. These small differences in values already very low, are not enough to account for the vast difference in growth observed between the good and bad areas. Furthermore, the cacao was planted only two years earlier in planting holes enriched with pen-manure, and the manure may still be expected to counteract any effect caused by small nutrient differences in the soil.

The physical data show a marked difference between the pits, however. Here the profile in the " bad area " shows a distinct orange band at 15-21 inches, which appeared to be more compact and sandy than the soil above and below. No such layer was found in pit No. 2 in the good area. This orange band has a higher fine sand content than the soil at the same depth in pit No. 2. Percolation rate measurements show that movement of water is very impeded in the orange layer (rate 0.25 c.c./min.) compared with the corresponding depth in pit 2 (rate 31 c.c./min.), and with the soil above. Further, the total pore-space is much less in the orange band than at the same depth in pit 2. The orange band in pit 1, therefore, appears to offer serious impedance to movement of water.

The above results suggested that the poor cacao site was characterised by a compact, sandy, badly draining layer at 15-21 inches, which could be visually recognised by its orange colour. Attempts to trace the extent of this

band by augering were not successful, owing to the difficulty of visual observations on auger samples. Accordingly, a number of small pits 2 feet deep were dug to ascertain the extent of the orange layer and to discover whether it did in fact coincide with areas of bad cacao. The pits were arranged radially outwards from pit 1, and several other pits were prepared in other parts of the field, in the less well marked " bad areas " and in surrounding good cacao.

The pits did not fall into two distinct classes—those with and those without the orange bands, so that as many as 22 pits were found necessary. Profile observations were made in the pits and considered in relation to the condition of the nearby cacao. It was found that the pits in the worst areas of cacao did show a distinct orange layer 6 inches broad or more. Where the cacao was satisfactory, the orange layer is much thinner and less distinct, or entirely absent. Only one pit showed the orange layer surrounded by good cacao, and this was situated in a narrow region of good cacao between two well marked " bad areas."

The conclusion drawn is that, in this region, the soil is characterised by " lenses " of fine-grained, sandy, compact material, varying in thickness and extent. Where this material occurs in a deep well-marked layer, drainage is markedly impeded, and the cacao is in very poor condition, but where the layer is absent or is thin or broken, and near the edges of such lenses, the cacao is satisfactory.

Elsewhere in the field, a pit in good cacao showed a uniform concolorous profile to 24 inches, indicative of free drainage. Pits in less well-marked areas of unsatisfactory cacao showed no orange band, but sepia mottling appeared at 16-18 inches depth, whereas elsewhere in the field mottling generally appeared at 24 inches or below. This again is indicative of drainage impedance, but these two areas appeared to be slightly low-lying and flat in contrast to the general slight slope of the field. Here drainage may be impeded by topographical rather than soil features.

TABLE I

Chemical and physical soil data from pits in " good " and " bad " areas.

Lower depth (ins.)	pH (Normal) Glass Electrode	Organic Matter %	Total Nitrogen %	C/N Ratio	Available P_2O_5 p.p.m.	Exchangeable K_2O p.p.m.	Sand Medium %	Sand Fine %	Percolation Rate cc./min.	Total pore-space Vol. %
Pit No. 1 (Bad Area No. 1)										
3	5.4	2.7	0.17	9.2	10	66	6	35	—	63
6	5.4	1.9	0.15	7.2	5	39	8	33	29	55
9	5.4	1.7	0.13	7.3	6	—	6	38	—	—
15	5.4	1.2	0.11	6.5	0	—	8	30	26	54
21	5.5	0.5	0.05	5.6	6	—	4	45	0.25	45
25	5.6	0.4	0.05	4.3	0	—	19	45	—	—
Pit No. 2 (Good Area No. 2)										
3	5.6	3.5	0.21	9.3	17	43	7	38	—	60
6	5.8	2.4	0.16	8.6	11	47	11	41	40	55
9	5.7	2.0	0.16	7.3	8	—	4	29	—	—
15	5.1	1.8	0.14	7.3	0	—	2	24	18	53
21	5.2	1.6	0.14	6.6	8	—	2	28	31	55
25	5.3	1.0	0.10	6.0	9	—	6	34	—	—

TABLE II

Chemical soil data from auger samples in good and bad areas.

Description	Lower Depth ins.	pH (Normal) Glass Electrode	Organic matter %	Total Nitrogen %	C/N ratio	*Available* P_2O_5 p.p.m.	*Exchangeable* K_2O p.p.m.
Bad Area No. 1	6	5.4	2.3	0.15	8.6	7	35
Good Area No. 1...	6	5.7	2.9	0.19	8.7	7	43
Bad Area No. 1	12	5.4	1.5	0.11	7.7	0	—
Good Area No. 1...	12	5.4	1.9	0.15	7.6	0	—
Bad Area No. 2	6	5.4	2.6	0.20	7.5	0	45
Good Area No. 2...	6	5.6	2.7	0.17	9.1	8	49
Bad Area No. 2	12	5.2	2.0	0.15	7.7	0	—
Good Area No. 2...	12	5.4	2.0	0.15	7.7	8	—
Bad Area No. 3	6	6.2	3.1	0.19	9.5	26	49
Good Area No. 3...	6	6.1	2.5	0.17	8.4	19	43
Bad Area No. 3	12	6.1	2.1	0.14	8.5	24	—
Good Area No. 3...	12	5.8	1.8	0.14	7.6	18	—

(A contour map with a vertical interval of 2 feet 6 inches prepared by J. P. Watson and E. L. Birse does not show this variation, because of the large vertical interval.)

The presence of material of different composition and characteristics in layers and lenses of this type is not unusual in alluvial soils.

The problem was overcome by sinking deep pits (6-10 feet deep) in the " bad " areas, which reached the gravel beneath, and running surface drains from the affected areas into them. Subsequently the whole field has been provided with frequent surface drains. The drainage pits were observed to carry away a large volume of water after rains. The growth of the cacao improved immediately they were dug, and has since been satisfactory, although the affected trees are still inferior to those in good areas, owing to their early setback. Recovery was notably most rapid in the case of affected trees in plots receiving nitrogen fertiliser.

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Lime-induced Chlorosis of Cacao Seedlings

by

G. Havord.

Cacao in Trinidad frequently exhibits a characteristic interveinal leaf chlorosis, both in the field and in potting baskets in the propagators. Usually only the younger leaves are affected, the chlorosis disappearing as the leaves mature, but in severe cases most of the leaves on the tree may be chlorotic, and premature leaf fall and frequent flushing ensue. The symptoms have been ascribed to iron deficiency. Foliar sprays of iron sulphate successfully cure the symptoms, at least temporarily, and are now standard practice in propagators. Diagnostic foliar injections of iron have given positive responses. Soil applications of Ferrosene (the iron complex of E.D.T.A.) have been effective on seedlings grown in baskets. Differences in susceptibilities between the ICS clones have been noted, and the chlorosis has been found more severe under high light intensities. The causes of the chlorosis have been stated to be a soil pH higher than 6.8 to 7.0 and/or poor soil aeration due to impeded drainage, either condition accentuating the effect of the other, so that chlorosis is more severe in wet weather (Evans *et al.*, 1950, 1952, 1953 ; Murray, 1953). General observation by the writer has confirmed that the chlorosis is most apparent on calcareous soils, particularly in badly drained sites, and seems to be accentuated in rainy periods. In addition, it has been noted that the chlorosis is generally only severe when the soil contains free calcium carbonate at or near the surface, and is low in organic matter (usually the results of erosion).

A pot experiment was carried out to determine the effects of improving the organic status of a highly calcareous soil, and of deliberately over-watering the plants, on the development of the chlorosis in cacao seedlings.

Experimental

Cacao seedlings were grown in earthenware pots under soil treatments based on Montserrat clay-loam (" Chocolate Soil "), a highly ferruginous soil described by McDonald, Hardy and Rodrigues (1933) and by Chenery (1952). A heavily eroded, highly calcareous sample, low in organic matter, obtained from a steeply sloping site where cacao exhibited the chlorosis, was the basis of all treatments. Organic material was supplied in two forms:—highly humic surface soil crumbs taken from a little-eroded flat near to the first site, and a compost made from sawdust previously used as stable bedding ; and in various ways:— as surface layers of two thicknesses, each with and without added lime, and in addition incorporated throughout the soil at two levels. This resulted in the following eleven treatments :—

(1) Pot filled 6 inches deep with the highly calcareous soil (" Control.")

(2) Pot filled 5 inches deep with the highly calcareous soil, plus 1 inch layer of crumb soil.

(3) Pot filled 4 inches deep with the highly calcareous soil, plus 2 inch layer of crumb soil.

(4) and (5) As (2) and (3), but using 1 inch and 2 inch layers of compost.

(6-9) As (2-5), but with 20% calcium carbonate mixed with the organic layers.

(10) Pot filled 6 inches deep with 20% compost and 80% calcareous soil (by weight), intimately mixed.

(11) Pot filled 6 inches deep with 30% compost and 70% calcareous soil (by weight), intimately mixed.

Table I.

Chemical analyses of the materials used.

Sample	pH (normal) Glass Electrode	Organic matter %	Total N %	C/N ratio	P_2O_5 p.p.m.	K_2O p.p.m.	Free $CaCO_3$ %
					Available	*Exchangeable*	
Calcareous soil...	7.5	1.9	0.12	9.0	18	248	30.9
Humic crumb soil	6.3	19.6	0.88	12.9	600	1,094	0
					Total	*Total*	
Sawdust compost	5.7	72.9	0.67	59.0	1,750	2,060	0

The treatments were replicated six times, and arranged as six randomised blocks.

The pots were fitted with a device to allow for watering from below, maintaining excellent water and air relations in the soil and preventing excessive drying out or water-logging, similar to that described by Schroo (1953). Cacao beans (ICS 39, open pollinated) were planted, three per pot, and the pots set up under banana and *Gliricidia* shade. For the first four weeks they were watered from the top on each day when there was little or no rain, and thereafter daily from below (the dry season by then had begun). Three grams of ammonium sulphate were watered into each pot 3 weeks after planting and thereafter at 8-week intervals, to guard against the development of a chlorosis due to nitrogen deficiency (possible due to the low organic nitrogen status of the " control " soil, and the use of fairly fresh compost).

Approximately 21 weeks after planting, three blocks were transferred to a greenhouse where they were subjected to almost constant watering from a fine spray for nearly eight hours a day. The other three blocks remained in the open and were allowed to dry out to a much greater degree than previously by suitable adjustment of the draining device and infrequent watering.

The development of chlorosis was noted after 4, 9, 14, 18, 25, 35 and 42 weeks. The intervals were irregular since, except in the control plants, the chlorosis symptoms largely disappeared as the leaves matured and were thus most readily observed on a young, just hardened flush. Marks were awarded to each plant in each pot as a measure of the degree of chlorosis on a scale of 0 to 5, as follows :—

0 No chlorosis.
1 Very slight chlorosis.
2 Slight chlorosis.
3 Marked chlorosis.
4 Severe chlorosis.
5 Very severe chlorosis.

To preserve uniformity in marking, a coloured chart was prepared illustrating the degree of chlorosis associated with each mark. The data were treated statistically in two ways. First, the average mark for each pot was placed in order of merit for each block and assigned a score, using Table XX of Fisher and Yates (1948), and the variance of the scores analysed (a slight modification involving an extension of the Table XX was necessary after the split for moisture treatments). In the second method, the average marks for each pot were converted to percentages by multiplying by 20, and then transformed to angles and these subjected to analysis of variance. In each case substantially similar results were obtained by either method. The first is probably more rigid, but only indicates whether significant differences existed between degrees of chlorosis. Only results based on the second

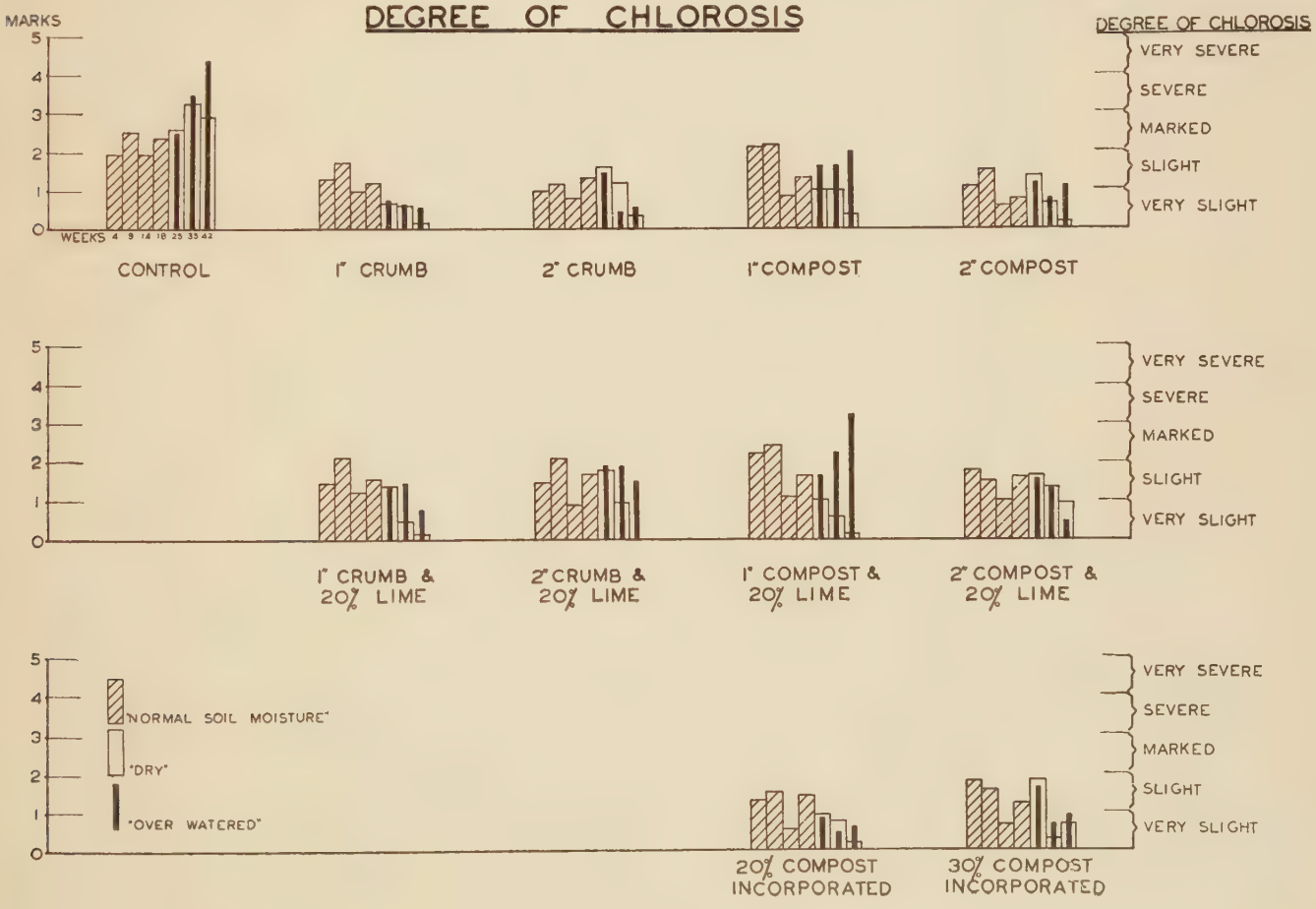

FIGURE 1

TABLE II

Mean marks converted to percentages and transformed to angles, for each treatment.

Age (weeks)	Wet or Dry	Treatment: Control (calcareous soil)	1 in. soil crumb	2 in. soil crumb	1 in. compost	2 in. compost	1 in. soil crumb and lime	2 in. soil crumb and lime
4	—	38.5	30.8	25.7	40.5	27.6	31.5	35.5
9	—	45.6	36.7*	28.8***	41.5	32.7***	40.0	40.1
14	—	38.5	26.0*	21.2***	23.6**	18.2***	32.6	25.8**
18	—	43.8	29.3***	31.2**	31.1**	22.4***	34.6*	35.4*
25	Dry	47.7	20.6	35.2	24.6	30.9	30.6	36.5
	Mean	47.3	21.1***	33.8**	29.8***	30.1***	30.8***	37.1*
	Wet	46.9	21.7	32.6	35.0	29.4	31.0	37.8
35	Dry	58.1	17.5	28.5	25.2	13.1	17.2	25.0
	Mean	57.9	17.9***	21.3***	30.2***	17.8***	24.8***	31.4***
	Wet	57.6	18.3	14.0	35.2	22.6	32.4	37.8
42	Dry	49.2	7.0***	7.0***	8.9***	6.1***	10.2***	0.0***
	Mean							
	Wet	68.8	18.7***	13.1***	39.1*	26.6**	22.6**	33.1

Age (weeks)	Treatment: 1 in. compost and lime	2 in. compost and lime	20% compost incorporated	30% compost incorporated	Mean Wet v Dry	Least Significant differences P=0.05	
4	41.6	35.9	30.2	36.8	—		Not significant
9	43.6	33.1***	34.3**	33.1***	—		7.1
14	31.1	26.0*	17.5***	26.9***	—		9.5
18	34.9*	32.7**	32.7**	26.9***	—		8.2
25	25.2	35.0	24.5	36.6	31.6 Not sig.	Between means of wet and dry for each treatment	9.2
	30.2***	34.4**	23.6***	35.1*			
	35.2	33.8	22.8	33.6	32.7		
35	19.1	26.1	20.6	10.2	23.7 Not sig.	ditto	14.1
	30.1***	28.3***	16.4***	15.6***			
	41.2	30.5	12.1	21.0	29.3		
42	5.1**	15.6*	5.1***	16.8*	11.9 Sig. P<0.05	Between means within "wet" or "dry"	27.5
	52.7	17.5***	15.9***	19.3***	29.8		

Means which differ significantly from control indicated by asterisks.

method are quoted, since they give in addition a quantitative measure of the degree of chlorosis. Growth heights were also recorded on each occasion observations were made.

The experiment was discontinued 42 weeks after planting. Leaf samples were collected from the whole experiment representing various degrees of chlorosis from the "wet" and "dry" treatments, taking leaves of similar age within "wet" and "dry" treatments. The roots from each pot were collected, separating those which had grown in the calcareous subsoil from those in the organic topsoil in the appropriate treatments, and repeatedly washed in distilled water, air-dried and weighed. The leaf samples (mid-ribs and petioles removed) and the roots from each control pot and each pot containing 20% compost incorporated were ashed and chemically analysed for total iron.

Results

The marks (transformed) awarded to each treatment at each observation and their statistical interpretations are given in Table II, and the degrees of chlorosis developed are illustrated in Fig. 1. Control plants exhibited a considerable degree of chlorosis throughout the experiment, which gradually became more severe, and became very severe in the overwatered pots. Four weeks after planting all plants were less chlorotic than controls except those receiving 1 inch of compost, with and without lime; but differences were not significant. Thereafter chlorosis was slight or very slight on all treated plants, and became significantly less than in the control plants. The chlorosis persisted longest in those plants receiving only 1 inch of organic material and in those receiving organic material mixed with lime. After the imposition of the two different

moisture treatments, chlorosis virtually disappeared in all "dry" plants treated with organic materials. The chlorosis shown by overwatered treated plants was notably more severe than that shown by the correspondingly treated dry plants only in those plants receiving 1 inch and 2 inches of crumb soil mixed with calcium carbonate, and in those receiving 1 inch of compost, i.e., in those plants in which chlorosis had been more noticeable in the earlier weeks. (The moisture × organic treatment interaction did not attain significance, however.)

Growth rates for each treatment are shown in Fig. 2. Undue importance should not be attached to differences between control and treated plants since these may be due to increased availability of nutrients from the organic amendments rather than be associated with the chlorosis. The curves do, however, indicate that growth rates were satisfactory in the treated plants, and were markedly reduced upon the imposition of the overwatering treatment. Root weights indicated that roots ramified throughout each pot, and were not concentrated in the surface organic layer.

The results of the chemical analyses of leaves and roots for iron are given in Table III. The leaf analyses do not show a consistent relationship between total iron content and degree of chlorosis. However, the iron content of "dry" non-chlorotic leaves was 110 p.p.m. Fe in air-dry leaf material, whereas chlorotic "dry" leaves contained nearly twice this amount, and all the "wet" leaves contained five to seven times this amount. An Fe content of 110 p.p.m. would be regarded as normal for a healthy cacao leaf. Root analyses again failed to give consistent differences between treatments which had markedly affected the development of chlorosis, but iron levels are very high, ranging from 0.17 to 0.44%. (The risk of contamination with soil is always present in root samples despite precautions to avoid it, and this may explain the single very high value of 1.75% Fe.) The conclusion is that the chlorosis is not due to failure to assimilate iron from the soil, but is associated with non-availability of iron within the plant.

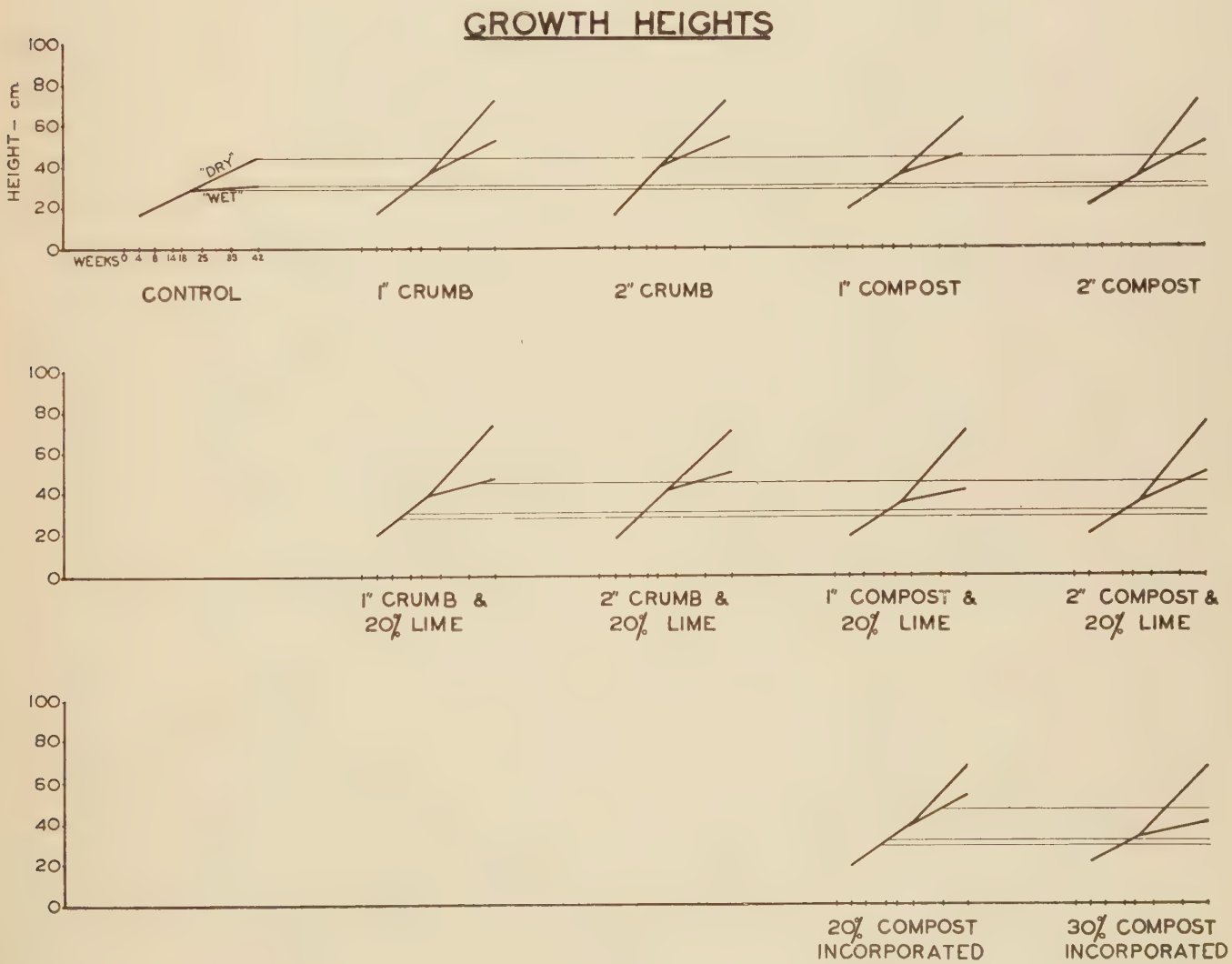

FIGURE 2

TABLE III

Iron content of leaves as percentage Fe in air-dry material.

	Degree of chlorosis			
	None	Slight	Marked	Severe
Wet	0.060	0.078	0.064	0.067
Dry	0.011	0.020	0.021	—

Iron content of roots from triplicate plants, as percentage Fe in air-dry material.

	Non-chlorotic (20% compost treatment)			
				Means
Wet	0.44	0.31	0.29	0.35
Dry	0.23	0.28	0.17	0.23
	Chlorotic (control treatment)			
Wet	(1.75)	0.21	0.17	0.19
Dry	0.33	0.22	0.24	0.26

Summary and Discussion

The experiment has demonstrated that cacao seedlings can be grown in a soil containing as much as 30% calcium carbonate, provided that it has adequate organic content either as a surface layer or incorporated in the soil. Under these conditions, only slight chlorosis developed and this only on young leaves, disappearing as the leaf matured, and chlorosis became negligible if the plants were watered sparingly.

The finding that lime-induced chlorosis is not due to failure of the plant to assimilate iron owing to high soil pH rendering it insoluble is in accord with the results of recent research on other species (Thorne, Wann and Robinson, 1950; Iljin, 1952). Lindsay and Thorne (1954) as a result of solution culture experiments suggested that lime-induced chlorosis may be caused by increased bicarbonate ion concentration in the soil solution, and pointed out that applications of organic manure would be expected to increase this concentration and thus increase chlorosis. The present experiment has shown that in the case of cacao seedlings the addition of organic amendments to the soil has reduced chlorosis.

Acknowledgments

The experimental work up to the time the plants were 25 weeks old was carried out by Mr. M. G. Hawson (postgraduate student) under the author's supervision. The iron analyses of leaves and roots were carried out by Mr. J. Spector. Thanks are due to Mr. F. W. Cope for advice on statistical matters.

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The Flavour Assessment of Cacao

by

K. W. De Witt

The flavour assessment of clonal cacao for research purposes has, for several years, been a problem of some magnitude. The Cacao Scientific Advisory Committee, representing British chocolate manufacturers, have rendered much assistance in this respect. However, as increasing amounts of clonal cacao have reached the bearing stage during the past few seasons, it has become apparent that it would be necessary to assess samples at the College in order to deal with the larger volume of experimental material. The tasting panel described below was organised at the beginning of the 1953-54 season, and has been operated continuously since then.

Originally, twenty members of the College staff volunteered to act as tasters. Usually, the number of tasters available at any one time varies between ten and twenty. The panel, consisting of six members, is selected from the available tasters. Four members of the panel are changed every two weeks, and two serve permanently, in order to provide continuity. At the height of the season, when a large number of samples are to be tested, two panels are operated simultaneously. In this case, one of the permanent tasters serves on both panels. Each member of the panel is presented with a sample of chocolate, distinguished only by a number, on five mornings in the week. The assessments are recorded on a standard form. The design of the forms finally evolved during the first season's operation is shown in Table I.

TABLE I

Taster.....Date.....Sample No.....				
Chocolate flavour	Strong	Moderate	Weak	Absent
Auxiliary flavour	Pronounced	Present	*Nature*.....	
Bitterness	Present	Absent	Unpleasant	
Astringency	Absent	Present	Pronounced	
Acidity	Pleasant	Absent	Unpleasant	
Off-flavours	*Nature* .....Present		Pronounced	
Comments				

The taster checks the form in the appropriate places. Comments, usually dealing with the general impression made by the sample, are encouraged. In the tasting form originally used, bitterness and acidity were classified in the same way as astringency, i.e., as " absent," " present " and " pronounced " in decreasing order of desirability. It was observed by tasters, however, that a moderate degree of acidity and bitterness is a desirable feature of the best chocolates, those entirely lacking in these characters being dull and insipid. An attempt is made in the forms at present in use to distinguish between the " pleasant " bitterness and acidity of a good chocolate and the " pronounced " bitterness (usually associated with a high degree of astringency) of underfermented cacao. The tasting form is so arranged that desirable characteristics lie on the left-hand side of the form and undesirable features on the right. This is done in order that the taster's general reaction to a sample may be gauged at a glance, from the general position of the check-marks on the form. There is no provision for assessment by a numerical system of marking. Several tasters like to include a numerical estimate of chocolate flavour in the " comments " section, for comparison with samples previously tested, but such scales of marking depend purely on the individual.

For collating purposes, the combined assessments for each sample are transferred to a clip-card. On each card is recorded the origin and method of fermentation of the sample, the tasters, and the individual results of the test for each characteristic. At this stage, it is necessary to assign numerical values to the assessment in order to obtain an average, so that the mean results can be clipped on the card. In addition, the details of making-up of the chocolate sample, and the nature of the auxiliary and off-flavours are entered on the card, but not clipped.

By this means, a steady flow of samples from different experiments can be maintained, without the danger of confusing the records, and without the necessity of maintaining a different set of results for each experiment. All the cards referring to a given set of tests can be selected in a single operation. The capacity of the panel (estimated at 300-400 tests per annum) would be greatly reduced without this system.

Tasting Results

The precision of a tasting panel is limited by the inconsistencies between tests and tasters. In the case of a chocolate-tasting panel such as this one, there are several agencies at work which combine to lower its precision, as follows :—

(*a*) Differences between several fermentations of the same clone or mixture, due to the effects of inclement weather on the solar fermentary.

(*b*) Variations in the making-up of chocolate samples. Commercial cacao roasting is a skilled craft, and the standard procedure used for the panel samples is not necessarily the best for all samples. Further, considerable differences occur in the ease with which these samples are moulded into blocks, which result in differences in texture of the finished chocolate. Although care is taken to try to make all chocolate of a similar texture, there are uncontrollable factors which lead to granularity and the formation of surface bloom in many samples : these faults in moulding may well mislead tasters.

(*c*) Variations between the tasters. It has been found that tasters vary widely in their ability to detect the various flavours in chocolate : it appears, also, that tasters differ considerably in their understanding of " chocolate flavour " itself.

However, since the function of the taste panel, broadly speaking, is to distinguish only the very good and the very bad from the mediocre samples, in order to guard against the introduction of inherently poor cacaos and to indicate the better ones, a high degree of precision is not so important as a high capacity. While investigations are continuing towards the attainment of consistency in preparation and assessment, the panel eliminates from consideration the large number of unremarkable samples which would otherwise have to be sent abroad for assessment.

Chocolate Flavour

When the inconsistency between tasters concerning strength of chocolate flavour is examined in more detail, several interesting features emerge. Using five levels of chocolate flavour—" strong," " moderate-strong," " moderate," " weak " and " absent "—and taking one of the permanent tasters as a standard, an estimate of inconsistency may be obtained for any assessment by the difference between the assessed level of chocolate flavour, and that for the same sample by the standard taster. Assessments higher than the standard are taken as positive, lower assessments as negative. Thus, for a sample assessed by the standard taster as having " moderate " chocolate flavour, an assessment of " strong " chocolate flavour by another taster has an inconsistency of +2, a " moderate-strong " assessment, +1, a " moderate " assessment, 0, a " weak " assessment —1, and so on. Using these conventions, histograms of inconsistency for all the assessments for sixteen tasters are shown in Fig. 1a, in which the number of samples is plotted vertically for each degree of inconsistency. It can be seen that several factors are operating to produce the inconsistencies. There is, first, the random effect, producing a scattering about the mean. There are also a number of systematic inconsistencies, producing in some cases a displacement of the mean from the zero line, in others askewness. The nature of these systematic inconsistencies is shown by the more detailed analysis of Fig. 1 b, c and d, in which the samples are grouped according to their assessment by the standard taster into three sets, the " strong " to " moderate-strong " samples, the " moderate " ones and the " weak " ones respectively. There appear to be two types of inconsistencies : (*a*) that in which a taster becomes progressively more inconsistent, in the same (negative) direction, as the strength of chocolate flavour increases, as with tasters 2, 3, 4, 11 ; (*b*) that in which a taster's estimate of strong chocolates is lower, and of weak chocolates higher than the standard, as in tasters 5, 6, 8, 9, 10, 12, 14 and 15. In addition, a further departure from normal distribution arises in the " moderate " set, in that many

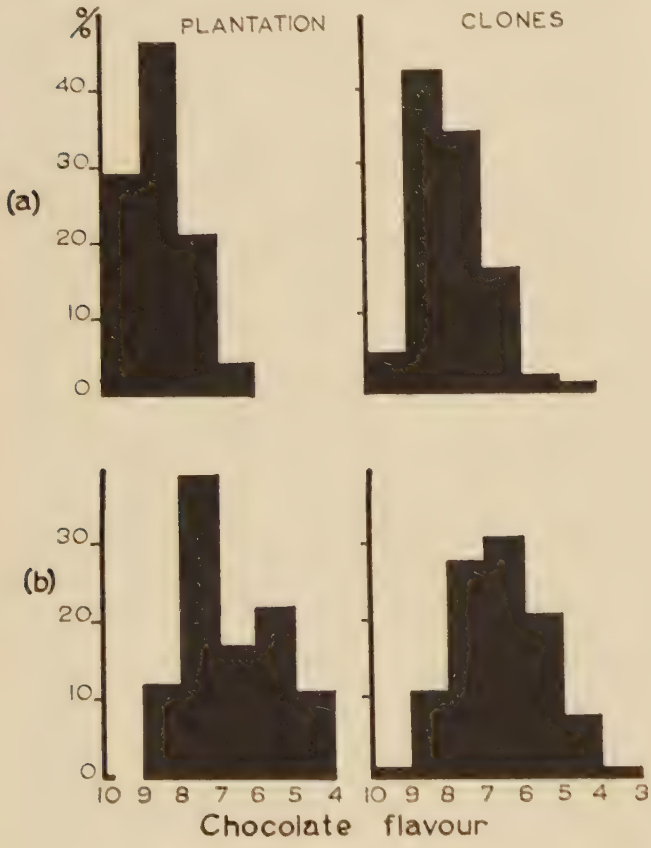

FIGURE 1

DEVIATIONS IN CHOCOLATE FLAVOUR ASSESSMENTS

Samples grouped according to variation in assessment from the standard taster's estimate. Positive deviations are higher than the standard, negative deviations lower. (*a*) All samples. (*b*) Standard assessment " strong " or " moderate-strong." (*c*) Standard assessment " moderate." (*d*) Standard assessment " moderate-weak " or " weak." Tasters numbered 1-16.

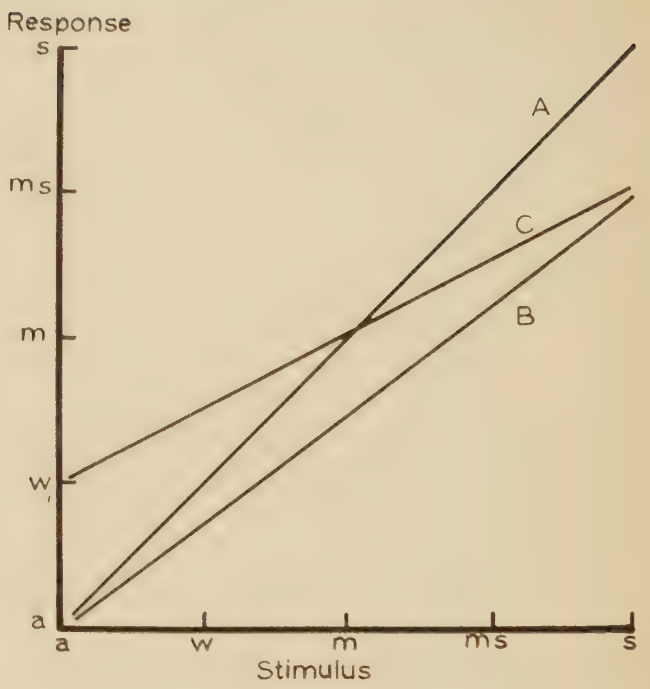

FIGURE 2

HYPOTHETICAL RESPONSE-STIMULUS RELATIONSHIPS FOR CHOCOLATE FLAVOUR

(*a*) Standard taster. (*b*) Low sensitivity. (*c*) Low discrimination. a = absent ; w = weak ; m = moderate ; ms = moderate-strong ; s = strong.

tasters have a bimodal distribution of inconsistency. This is caused by the reluctance of these tasters to distinguish between " strong " and " moderate-strong " samples.

These observations can be explained if it is assumed that a taster's response to a chocolate-flavour stimulus is determined by two factors, his assessment of the level of chocolate flavour with reference to a mental standard (" sensitivity ") and his power to distinguish between different levels of chocolate flavour (" discrimination "). On this hypothesis, the systematic inconsistency (*a*) above arises where a taster has a lower " sensitivity," i.e., he requires a stronger stimulus than the standard to evoke the same response, while (*b*) arises where the " discrimination " is lower, i.e., the taster, while agreeing with the standard as to the level of chocolate flavour in a moderate sample, needs a greater difference in flavour level to distinguish between this and either a weak or a strong sample. The difference is illustrated hypothetically in Fig. 2.

Since the samples included both clonal material and high-grade Trinidad plantation cacaos, it may be assumed that the range of intensity of chocolate flavour covered by these tests is fairly wide. A comparison of the chocolate flavour assessments by the standard taster for the commercial samples and the clonal samples is shown in Fig. 3a. There is a higher proportion of strongly-flavoured samples among the plantation samples than in the clones. This bears out the general experience of the panel, that the plantation samples are mainly distinguished by their strength of flavour, rather than by any special distinguishing feature in their auxiliary flavours, which are discussed below. Owing to the inconsistency between tasters already mentioned, this difference is not apparent in the combined assessments for the whole panel (Fig. 3b). In this case, the only difference between the plantation group and the clonal group is that in the plantation group there is a pronounced peak in the proportion of samples with a moderate chocolate flavour, while in the clonal samples, the distribution is nearer to a normal curve, with the maximum at a slightly lower value of chocolate flavour. The difference between the two sets of samples may be traced to two sources. One is that the solar fermentation method, while giving satisfactory fermentations under optimal conditions, is much more subject to inclement weather than is the plantation sweatbox. It is inevitable, therefore, that the clonal samples will include a higher proportion of less successful fermentations than the plantation cacaos. The other factor is the difference in composition of the samples. The clonal samples are made up from narrow range of genetic material, while the plantation cacaos contain an enormous variety of different types of cacao. It is to be expected that the clonal samples will include a considerable proportion of weaker-flavoured cacaos.

Auxiliary Flavours

Tasters also differ considerably in their ability to detect and distinguish the auxiliary flavours of chocolate. While some tasters can only determine whether an auxiliary flavour is present or not, using the general term " fruity " to describe it, others may use a range of terms to denote differences between auxiliary flavours. The maximum number of distinct descriptive terms used by any one taster is eight. Of these, the most important are those of the fruity range, " vanilla," " raisin," " wine," " prune " and " liquorice." A small number of the solar-fermented samples were described as having caramel or toffee flavours, which were not encountered in commercial samples. It is thought that such flavours are due to the method of fermentation. The frequency of occurrence of the commonest names for auxiliary flavours in 790 assessments by seventeen tasters is shown in Table II. As would be expected, there is a direct relationship between the abilities of tasters to detect and to discriminate between auxiliary flavours. This is shown by Fig. 4, where the discrimination of tasters (i.e., the number of distinct auxiliary flavours recognised) is plotted against their sensitivity (the percentage of cases in which an auxiliary flavour was detected). The relationship is statistically significant at the p=0.01 level of probability.

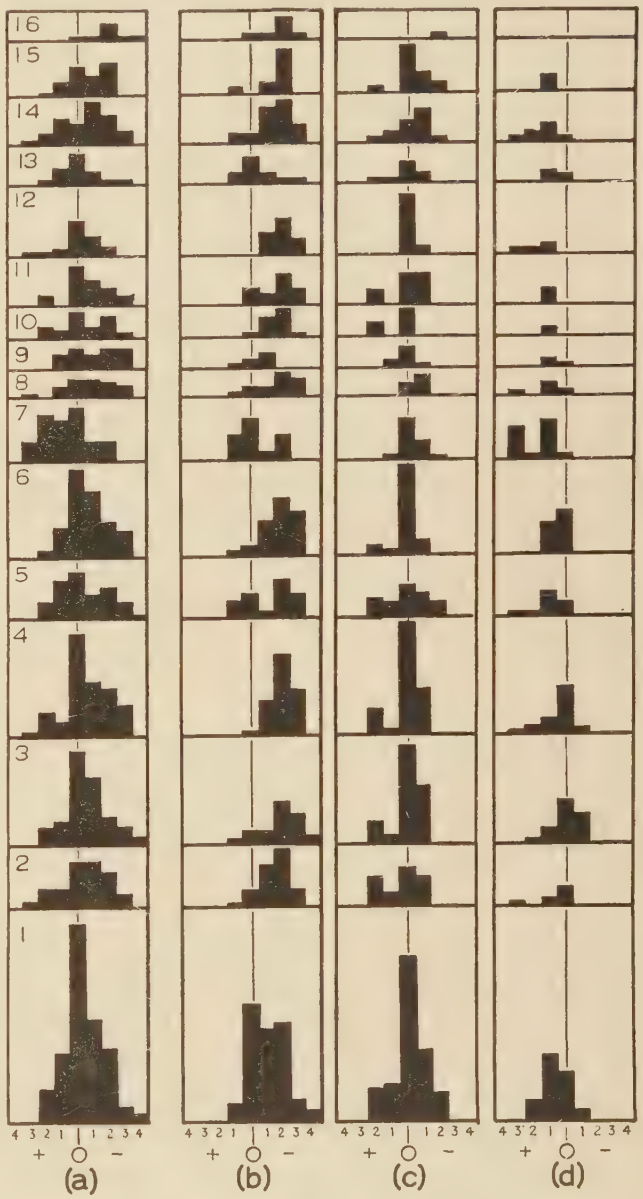

FIGURE 3

CHOCOLATE FLAVOUR ASSESSMENTS OF PLANTATION AND CLONAL CACAOS

(*a*) Standard taster. (*b*) Whole panel. *Vertical scale:* percentage of samples. *Horizontal scale:* chocolate flavour on scale of 0-10.

TABLE II

Types of auxiliary flavour.

Flavour name	Fruit	Vanilla	Raisin	Wine	Prune	Liquorice	Nutty	Caramel-Toffee
Times used	98	53	132	26	128	21	29	17
No. of tasters	11	9	14	6	10	5	6	11

The most common type of auxiliary flavour encountered in these tests was the fruity flavour of raisins or prunes, usually associated with Trinidad cacao. Nearly all samples have auxiliary flavours falling within the range vanilla-raisin-prune-liquorice, and can be grouped into two main classes, the " light " samples, where the auxiliary flavour is of the vanilla or raisin type, and the " heavy " samples, which have a deeper auxiliary flavour of the prune or liquorice type. This provides a convenient method for classifying the samples. For example, the plantation samples usually are of the " heavy " type ; Grenada samples were described as being of a deeper character than the Trinidad sample. Many of the clonal samples were classified as light flavoured cacaos, i.e., having auxiliary flavours of the vanilla-raisin type. It was also suggested by tasters that the light-flavoured cacaos had weaker chocolate flavours, and strong chocolates usually had auxiliary flavours of the heavy class. The extent of this correlation for a single taster is shown in Table III. It can be seen that, for this taster, there is a trend towards the deeper end of the auxiliary flavour scale in the stronger chocolate samples. This is significant at the $p=0.001$ level of significance. This correlation between auxiliary flavour and chocolate flavour is so high as to suggest that the agencies by which the two flavours are produced are very closely related to each other.

TABLE III

Relationship between type of auxiliary flavour and strength of chocolate flavour for one taster.

Auxiliary flavour	Vanilla-Raisin	Raisin	Raisin-Prune	Prune	Prune-Liquorice
Strength of chocolate flavour		No. of samples			
5	1	2	—	—	—
5½	—	1	—	—	—
6	2	5	1	1	1
6½	2	8	2	1	—
7	3	4	9	7	—
7½	2	6	7	13	—
8	1	1	4	23	5
8½	—	2	1	25	5
9	—	—	1	9	1

In the case of the pure clone samples, there is evidence that in most cases a clone gives the same kind of flavour in each fermentation. This is not invariably true, since while ICS 1 gives a highly characteristic light, weak flavoured cacao in most cases, two of the ten fermentations of this clone have produced heavier-flavoured cacaos. This modification must have been induced in course of fermentation.

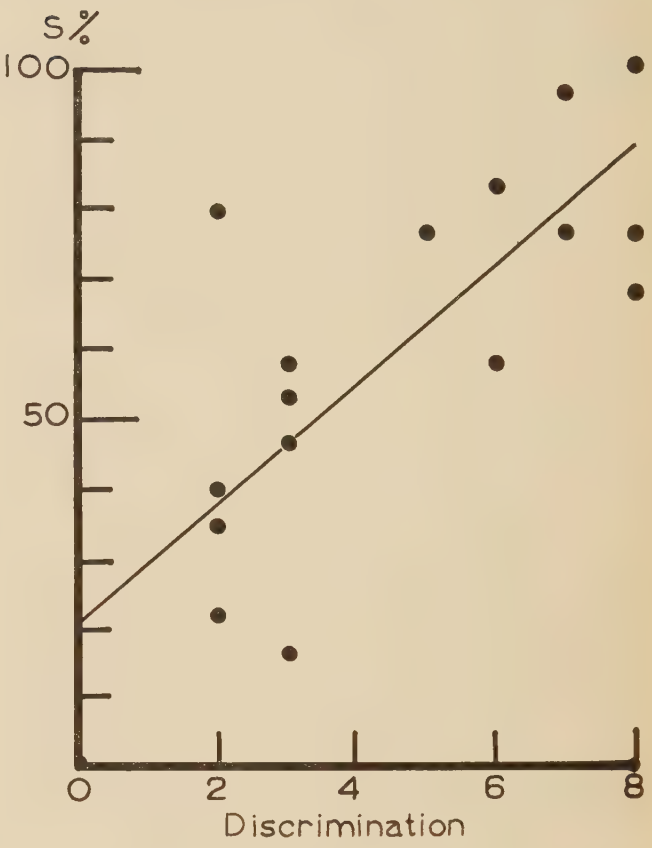

FIGURE 4

SENSITIVITY-DISCRIMINATION RELATIONSHIP FOR AUXILIARY FLAVOURS

s = percentage of all samples in which an auxiliary flavour was detected. Discrimination : number of different auxiliary flavours recognised, for seventeen tasters. Fitted line $D=20.68+8.463S$.

Owing to this modifying effect of fermentation, a number of repetitions of clonal samples are necessary before the inherent flavour class of a clone, under given conditions, can be determined. Tentatively, the clones ICS 1, 39 and 46 have been assigned to the light class, ICS 70, 44, 87, 95 and SCA 12 to the heavy class. The clonal samples prepared during the season included mixtures of up to six clones in known proportions. Too many inconsistencies occur in the assessment to be able to draw definite conclusions, but it is clear that in admixture, the flavours of the constituents may be modified, e.g., there are indications that mixtures can be made up, of which the flavour is better than that of the constituent clones. Mixtures in which this effect has been observed contain both light and heavy flavoured elements, and it may be that a blending or " balancing " of flavours occurs in such cases. It appears unlikely that any changes in the actual intensity of flavour could be brought about by this means.

Off-flavours

In the case of one clone, ICS 48, an off-flavour was observed in solar fermentations of this clone, by itself, and

in admixture with other clones, and also in a sample of ICS 48 prepared in the microfermentary. The descriptions given by testers were " walnut-skin," " earthy," " musty," indicating a flavour akin to that produced by internal mould. Examinations of the samples by the cut test, however, disclosed no apparent mould growth. These observations indicated that this clone possesses an inherent off-flavour, or, alternatively, is more prone to develop the flavour than other clones. Further investigations are being carried out to determine whether the off-flavour is always present in the clone, and whether there are any others in the ICS range showing the same feature.

The off-flavour most frequently found in the samples was that due to internal mould, usually described as " earthy " or " musty." This flavour was sometimes found in fresh samples, where the mould had developed during unsatisfactory drying weather, and was prone to occur in samples which had been stored for some time. The ability of tasters to detect the off-flavour does not appear to be related to their sensitivity to auxiliary flavours.

Conclusion

The operation of a tasting panel, where the available tasters are not familiar with the cacao trade, and where there is no satisfactory single standard of reference, has been described. The essential feature of the method is the large number of samples which are tasted in a season. The great variation between tasters renders it necessary to compare tasting performances in detail, using a large number of assessments. Hence it follows that some suitable system for recording assessments for ready reference, such as the clip-card system used here, is also desirable. Experiments are at present in progress on the application of statistical analysis to tasting results. The major difficulties are those of variations between tasters both in sensitivity and discrimination, and of variations between replicate samples. Variations between tasters of chocolate are not only a feature of unskilled panels, such as this ; it is known that requirements and definitions of " good " chocolates vary considerably between commercial firms. It is hoped that with the experience gained during the first year's tasting, it will be possible to improve the precision and consistency of the assessments by means of the knowledge gained of the performance of each taster. In the meantime, it has for the first time become possible to offer tentative guidance on the selection of clones for quality from the thirty already examined. It is appreciated that, on the whole, the clonal samples do not reach the standards of the best Trinidad and Grenada plantation cacaos ; investigations are proceeding to determine whether the difference is due to a difference between seedling and clonal cacaos, or whether it is an artefact due to the differences in fermentation. On the other hand, with the exception already mentioned, ICS 48, it is clear that the clonal material is not actively undesirable, and that it can be fermented to give a good saleable cacao. Using the I.C.T.A. panel as a safeguard against the introduction of undesirable selections, there should be no difficulty in maintaining this position while investigations directed towards the improvement of flavour are continuing.

Acknowledgments

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